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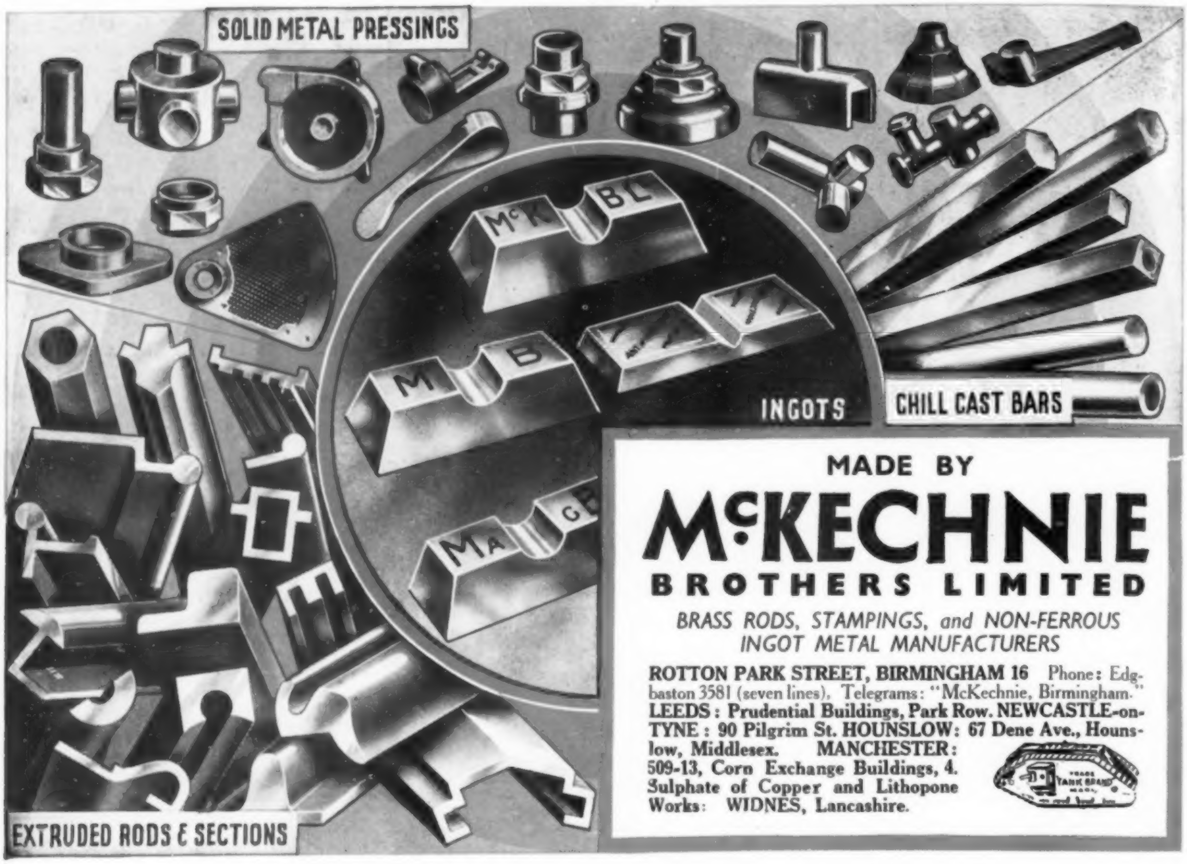

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(INCORPORATING THE METALLURGICAL ENGINEER.)

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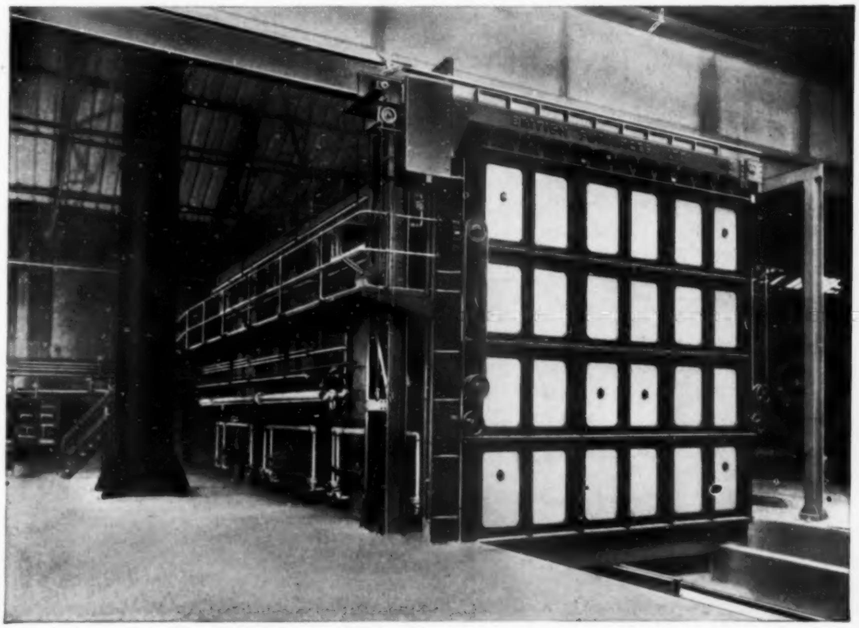
A Stress-Relieving Furnace for Welded Structures

By L. G. A. Leonard

Carbon and low-alloy steels containing more than 0·15% C are hardened when the zone next to a weld cools from the welding heat. Usually, in welded structures, when these zones exceed 200 Brinell, a stress-relieving treatment is given in order to remove the brittle effect, and this article describes a large furnace specially designed for this purpose.



General View of Stress Relieving Furnace

THE use of welding for constructional and other purposes has increased to such an extent during recent years that it has become necessary to develop subsidiary equipment to permit the accomplishment of high-quality work at an economic cost. Much attention, for instance, has been directed to the stresses, and the localised hardening resulting from the welding of structures or vessels, and investigations have shown that their effects can be substantially reduced by heat-treatment. It is now recognised that a stress-relieving heat-treatment is advantageous to the welded structure or vessel. Many insurance companies have, in fact, formulated rules to cover the stress-relieving of welded pressure vessels. Such a furnace was recently installed at the works of Daniel Adamson and Co., Ltd., and since it incorporates many interesting features, the main particulars will be of interest.

A preliminary study of the conditions were necessary to decide upon the fuel to be used, as the furnace was required for the stress-relieving of welded-pressure vessels and of considerable size. Automatic temperature control, uniform heat distribution, and the clean, non-oxidising furnace atmosphere which could be maintained by the use of town's gas were favourable to its use as a fuel; the elimination of handling, and the inherent advantage of the use of clean fuel, together with the favourable rate offered by the local gas company, resulted in the decision that town's gas would be the most suitable.

The Furnace

The furnace, which was built by British Furnaces, Ltd., is of large size. It is of the car-bottom type and 36 ft. long, 14 ft. wide, and 14 ft. high. The welded structure to be heat-treated is loaded on a bogie and moved into the furnace by means of a hand-operated winch, but the design of the bogie is such that one man can easily charge and discharge the furnace. Roller bearings are used for the bogie-wheel axles, and sand seals on the sides and ends of the car to prevent the escape of hot gases to the undercarriage.

The walls are built of lightweight insulating refractory, backed up with efficient diatomaceous earth insulation bricks, all of which are enclosed in a strong welded steel casing heavily braced to ensure rigidity. Due to the difference in weight between insulating refractory and firebrick, it will be realised that a tremendous saving in the amount of heat required to heat up the furnace is made possible by the substitution of this material for ordinary firebrick. The insulating refractory also enables the furnace to be held at temperature with much less fuel than would be required if firebrick were used.

A very desirable feature in a stress-relieving furnace is that the walls shall have a low heat storage capacity, which will enable fast heating and controlled cooling. The low heat storage capacity also affects the temperature control, as the action of the automatic control equipment is made more sensitive. As the bogie has to take very heavy loads, insulating refractory has only been used in the spaces between the firebrick piers which extend above the top surface to allow for circulation of gases under the charge.

The roof is of the flat suspended type, each block of insulating refractory being composed of three dovetailed parts, the whole roof being flexibly hung by means of hanger rods and plates.

Owing to the necessity of accommodating the door below the track of the crane used for loading, it was impossible for it to be of the usual vertical lifting type. It was, therefore, designed to open to the side and to be controlled by two chains in a similar manner to a floor-operated travelling crane. The electric traversing motor and gearing is contained in an insulated case on the left-hand side of the door. One advantage of this chain-door moving control equipment is that the operator must pull on the chain all the time the door is being moved. There is no possibility of any accidental movement.

The door is constructed of interlocked blocks of a very lightweight insulating refractory, threaded on vertical bars of high-temperature tensile steel, which are fastened to the traversing trolley at the top and support the door from the bottom. Arrangements are made on the sectional cast-iron frame to clamp the door, when in its closed position, both at the top and bottom without the necessity of the operator using a ladder.

Gas-Burner Equipment

Thirty-six low-pressure velocity burners arranged in three zones are used for heating, these zones being again subdivided into four groups of burners. The use of over and under cross-firing obviates direct flame impingement upon the work and also creates a recirculation of hot gases. Each burner will give a constant gas/air ratio throughout the whole range of its consumption without attention on the part of the operator. An electrically driven fan, situated on top of the furnace, supplies air at a pressure of 1 lb. per sq. in. to the burners. The pressure of the gas is 4 in. w.g., and this is reduced to zero by means of governors, one on each group of burners. The air is then utilised to draw into the venturi throats of the burners the required quantity of gas.

Circulating Fans

For heating at low temperatures, such as those required for stress-relieving, the ideal method is by the circulation of a large quantity of hot gases at a high velocity. In this furnace six recirculating fans are employed—of special design to withstand temperatures as high as 920° C.

The shafts and bearings are water-cooled, funnels being situated near each fan, and also near the central control board, so that the flow of water can be observed. The water is delivered by a stationary tube inside each fan shaft to a point immediately behind the fan wheel, being used for cooling where most required. A platform extending round the furnace enables the fans and burners to be inspected with ease. A unique feature is the employment of these fans for another purpose apart from recirculating gases.

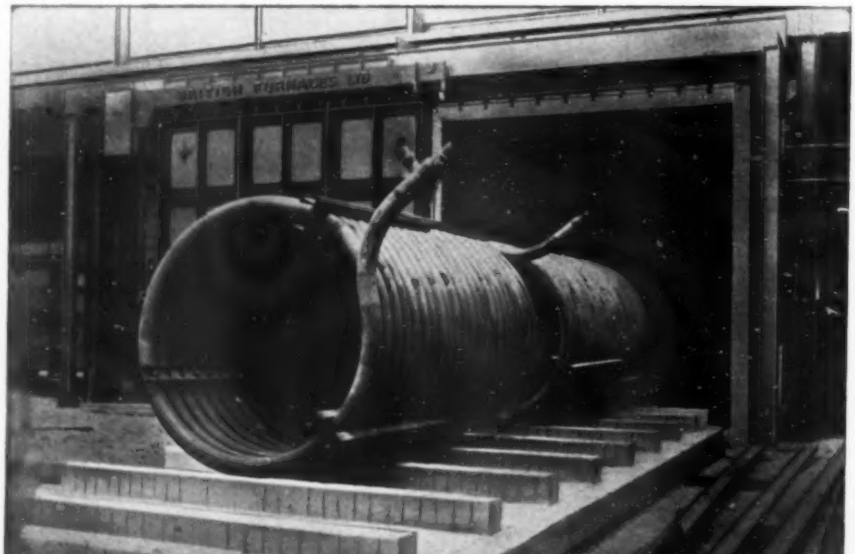
Some distance away from the stress-relieving furnace is a large plate-heating furnace built by the same firm, which normally operates at a temperature of 1,150° C., and which is 18 ft. 6 in. wide × 18 ft. long × 6 ft. 6 in. high inside. The waste gases from this furnace can be pulled through underground flues, built of insulating refractory to the stress-relieving furnace by the six electrically driven fans described above.

The use of waste heat in this manner gives very considerable economies in the working of the stress-relieving furnace. The change-over from heating by waste gases to direct heating with recirculation is easily accomplished by opening the recirculating dampers and closing the waste-gas inlet dampers.

Automatic-Temperature Control.

As previously mentioned, the furnace is divided into three zones, which are controlled independently from thermocouples extending through the roof. Before a charge is heated the thermocouples are dropped into a position a few inches from the top of it. Other thermocouples are arranged in the side walls so that temperatures on the lower sides of the structure under treatment can be recorded. Control is effected from three thermo-couples and records obtained of the temperature at six other points.

The Electroflo longscale indicating controller for each zone is clearly indicated, and is situated above the starters of the circulating fans for that zone. On the right-hand side of the panel is a longscale pyrometer for measuring the temperature of the plate furnace, and also the temperature of its waste gases. At the top of the panel is an electric clock which is connected to an alarm bell, and when the furnace has been brought to temperature the operator can set the soaking time to correspond with the thickness of the metal being heated. When this time is completed the bell rings and the charge is withdrawn or allowed to cool inside the furnace, depending upon the heat-treatment required. The control instruments are connected to damper- and valve-operating units fixed on top of the furnace, and are arranged to give the amount of flue-opening proportional to the quantity of gas being burned. The same control also operates when the furnace is being heated by waste gases from the plate furnace. In spite of the large internal volume, it is possible to hold a temperature of 620° C. within plus or minus 5° C.



View of Furnace with Loaded Bogie

Furnace Capacity

The furnace has been designed to take pressure vessels weighing from 25 to 30 tons, and can be used for normalising at a temperature of 920° C., as well as for stress-relieving at 600° to 650° C. A 25-ton charge can be heated in the furnace to a temperature of 620° C. in 5 hours and soaked for 1 hour with a gas consumption of 61,500 cub. ft., the was having a calorific value of 475 B.t.u.s per cub. ft. When waste gases are available from the plate furnace, the quantity of gas to be burned in the stress-relieving furnace is almost negligible.

Fatigue Strength of Drilled and Notched Steel Test-Pieces under Alternating Tensile and Compression, Bending and Torsional Stress

THE object cf modern methods for testing materials is to determine methcds for calculating the physical properties of materials under stresses corresponding to thcse experienced in practice. This is attempted by determining the fatigue resistance cf constructional parts dimensioned exactly as for actual use, or test-pieces of simple fcrm, by measuring the strengths and their distribution over the surface of actual constructional parts or of a model, by means of optical, electrical, or mechanical measuring methods, when under the influence of an external load, and further, by calculating the distribution of the strengths. Recent development of the testing of materials is surveyed by Korber and Hempel,* and because of its unusual interest it is reviewed in some detail here.

It is well known that the service life of constructicnal parts under fatigue stress is shortened considerably by the transition frcm one cross-section to another by means of flutes, notches, holes, etc.; attempts have therefcre been made to improve the fatigue resistance of such parts by cold-working, nitriding or the addition cf residual stresses. From the resulting figures and knowledge obtained by many investigations it is important to find out what relations may exist between fatigue resistance and test-piece form or notch form, how far these results harmonise with theoretical rules, and what conclusicns can be drawn with regard to the behaviour of the material under various ccnditions cf stress.

In order to apprcach, as far as possible, the actual conditions, it is necessary to determine the physical prcperties cn test-pieces of irregular form. For this reason, it is proposed to use the following relations: The strength calculated according to the theoretical formulae of elasticity by using the load and the effective cross-section may be called "nominal strength" (σ_n), the maximum strength below the elastic limit in the case of a static load "maximum strength" (σ_{max}), and the ratio $\frac{\delta_{max}}{\delta_n} = a_k$ "form cefficient." This figure is generally independent of the value of the nominal strength and cf the quality of the material, but dependent cn the form and dimensions of the constructional part and of the type of stress.

Whilst peaks cf static stresses do nct, or at least, only slightly increase the danger of fracture, the contrary is the case to a decidcd extent with alternating stress; but the high peaks of stress which locally take place and are marked by the figure a_k, do not fully operate. The reascn of this phenomenon is not yet understood: perhaps the flow cf material at the notch is hampered by the neighbcuring material which is nct so highly stressed, and supports, to some extent, the endangered position, or plastic deformations take place which reduce the peaks. As a measure cf the peak stress, which brings about the fracture of a notched constructional part under alternating stress, a notching coefficient β_k is used. This figure shows the fracture stress as the multiple of the nominal stress or, in other words: it is the ratio of the fatigue strength of a cylindrical test-piece with an ideal surface to the fatigue strength of a piece with transitions from one cross section to another. This coefficient is dependent on the type of stress, the dimensions of the constructional part, and the state of strength which may be caused by the shape of the part, as well as on the material, when the form of the notch is considered to be unchanged. Using the coefficients β_k and a_k, a third figure can be introduced, which may indicate the sensibility of the part concerned against notching $\eta_k = \frac{\beta_k - 1}{a_k - 1}$ i.e., the ratio of the actual to the theoretical surplus stress. In order to use these "sensibility efficients" in practice it is necessary to determine how these figures change for different materials if the form of the notching and the quality of the surface remains unchanged, but, in which the size of the test-pieces and the types of the stress are altered. Much work has still to be done, especially for checking the "form coefficient" in the case of test-pieces of different dimensions and for determining the "notching coefficients" β_k of different forms of notches and of various steels.

The highest values of β_k have been obtained by fatigue tests under bending and torsional alternating stress—i.e., by experiments with irregular distribution of stress over the cross-section, and with additional stresses at or near the bottom of the notches. The work under review has been carried out especially to determine the influence of cross-holes cf different diameter, and of notches of different depths, but of the same form, on alternating stress by tensile and compression for carbon as well as alloyed steels. Simultaneously, experiments were carried out, for comparison purposes, under the same conditions, but with bending or torsional alternating stresses.

STEELS INVESTIGATED.

C %	Si %	Mn %	P %	S %	Cu %	Cr %	Ni %	Mo %	V %	W %
0·02	Traces	0·37	0·052	0·025	—	—	—	—	—	—
0·21	0·17	0·26	0·035	0·035	—	—	—	—	—	—
0·39	Traces	0·72	0·017	0·027	—	—	—	—	—	—
0·64	0·11	0·75	0·020	0·052	—	—	—	—	—	—
0·77	0·11	0·87	0·031	0·023	—	—	—	—	—	—
0·11	Traces	0·47	0·010	0·023	0·19	—	—	—	—	—
0·19	0·39	1·35	0·032	0·032	0·42	—	—	—	—	—
0·47	0·35	1·75	0·034	0·032	0·17	—	—	—	—	—
0·31	0·29	0·48	0·007	0·006	—	2·05	2·07	0·33	—	—
0·34	0·28	0·45	0·012	0·009	—	2·17	2·20	0·36	—	—
0·44	0·24	0·79	0·024	0·025	—	1·52	0·39	0·32	0·25	—
0·43	0·27	0·58	0·012	0·015	—	0·92	0·30	0·33	—	—
0·30	0·38	0·53	0·011	0·004	—	2·51	1·22	0·23	0·22	—
0·20	0·18	0·38	0·014	0·005	—	1·56	4·20	0·06	—	0·79

Eight carbon and six alloy steels were investigated, the chemical and physical properties of which are given in the accempanying Table. The test-pieces of five carbon steels had a square section, and the remaining three were rectangular; the six alloy steels had a rcund section. Sizes and position of the notches and holes are illustrated by drawings. The experiments were carried out by means of five testing machines, of different construction, using the Wöhler methcd, and care was taken in cooling the test-pieces during the experiments by acid-free oil.

The coefficients β_k can be determined from the fatigue strength cf solid test-pieces, and pieces with holes and notches by means of the actual cross-section of the various specimens. A considerable part of the report, therefore, is taken up in calculating the actual cross-sections of the test-pieces, the resisting moments of the various specimens plotted against diameter of the hole or diameter of the test-piece, the effective test lengths, etc.

The results of the investigations are given by discussing the relations of:

1. Fatigue strength and tensile strength.
2. Notching coefficient and tensile strength.
3. Notching coefficient and notch angle.

Although these results do not give rules of the behaviour of notching coefficients for all materials under varying conditions, the following statements can be considered to be largely confirmed:

The fatigue strength of solid specimens and specimens with transitions from one cross-section to another primarily depends upon the tensile strength of the material. Even small notch depths or small holes have a great influence in decreasing the fatigue strength. The notching coefficients β_k generally rise with increasing tensile strength, an exception being the notching coefficients of specimens under torsional stress. The curves of the mean values of the notching coefficients, in the case of tensile-compression and bending stress, are very similar for notched and drilled test-pieces.

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*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforchung, Düsseldorf, Vol. XXI. No. 1.

Investigations of the influence of the notch angle on the notching coefficient show that the figures β_k remain unaltered for notch angles between 30° and 120° under bending and torsional stress, whilst the figures of the form coefficient α_k change in proportion to the notch angle.

The conclusion of the report is an attempt to decide the question, which of the five hypotheses of material strength or resistance may best explain the fracture of a specimen or the danger of flow of its material. For this purpose the results of the present investigations are compared with other published work, and the conclusion is drawn that where the ratio of the limits of torsional and tensile stress can be taken as 0·58, it is probably the best one; but it is not possible to consider this conclusion as valid argument, as there are still many points which need closer investigation.

Fire Hazards with Aluminium Paint

The conditions under which the use of aluminium paint becomes a fire hazard are extremely limited, when account is taken of its wide use in industry.

THE use of aluminium paint has become common practice in many works in connection with various types of plant and machinery. The paint is used both as a priming and anti-corrosive undercoat for steelwork, where the prevention of rust is of primary importance, and as a final coat for a very wide range of purposes. In spaces not unduly exposed to moisture, aluminium paint has proved entirely satisfactory, providing a suitable vehicle is used in mixing it, and the surfaces to which it is applied are properly cleaned. In addition to the protection of metal surfaces from corrosion, aluminium paint improves the resistance of metals to scaling at high temperatures, and, because of its high reflectivity, it is used to keep storage interiors cool. In view of these applications, it is important that implications to the effect that aluminium paint constitutes a fire risk, and consequently should not be used in situations where inflammable gas is liable to be encountered, be carefully reviewed.

The conditions under which sparking from aluminium-painted surfaces occurs have been well established, and can now be fairly clearly defined. Tests by an aluminium pigment manufacturer have been confirmed by the recent investigation undertaken by the Safety in Mines Research Board Laboratories, which shows that under certain conditions it is possible to produce sparks by striking an aluminium-painted ferrous surface.

When aluminium paint is applied to rusty surfaces of iron or steel and the paint film subjected to temperatures sufficient to break down the elastic structure of the binding medium, cracking and release of the film is liable to occur. If this surface is then struck with a steel or bronze implement a spark or series of sparks may be produced. This has been responsible for the assumption that in the presence of inflammable vapour a fire risk is established. Careful consideration of the facts, however, reveals that a series of conditions must be present before such risk can be established. These conditions, *all* of which need to be present, are as follows:

1. The paint is applied to a rust-coated surface.
2. The paint medium is such as to permit cracking or has been broken down by heating to a temperature of not less than 90° C.
3. Inflammable vapour in explosive concentrations must be present.
4. The paint surface conforming to conditions 1 and 2 is struck with a metal or other hard-material implement.

It is highly improbable that the complete combination of these conditions would ever be met with in practice. From several points of view, therefore, the presence of aluminium paint cannot in itself be considered as constituting a true fire hazard.

In the first place, it has been shown by the investigations that no sparking occurs when the paint is applied to clean steel or iron surfaces. Thus the presence of rust particles is a necessary factor in the promotion of sparking. From the viewpoint of maintenance alone, no paint should be applied to surfaces on which loose rust is present, always in painting procedure is it required that rusty surfaces be cleaned down prior to painting. In fact, it is the general practice to apply a rust inhibiter as a first coat. Also, in factories where explosive vapour or material exists, maintenance receives very careful attention.

Secondly, it is necessary to consider the stringent Home Office regulations which now govern the precautions to be taken to eliminate causes of sparking where inflammable vapours are present. The prevention of possible ignition arising from the use of aluminium paint does not appear to require more rigid regulations than those which guard against sparking by impact between ferrous implements or, for example, by shoe nails striking concrete or steel floors, closing gates, and so on. Moreover, the conditions under which maintenance is carried out are carefully controlled. All these conditions, it must be pointed out, are the subject of Home Office regulations.

So far as can be ascertained, the discovery of the sparking phenomenon referred to was made accidentally under conditions where inflammable vapour or gas in explosive quantities could not be present, and there does not appear to be any record of fires or explosions having been initiated from this source. It is understood that the investigations by the Safety in Mines Research Board are being continued, and their findings will be read with great interest by all executives who endeavour to use correctly materials which add to general efficiency.

This review, together with the information already published, will serve to indicate that the conditions under which the use of aluminium paint becomes a fire hazard are extremely limited, when account is taken of its wide use in industry. The discovery does, however, point to the fact that where such conditions do exist the adoption of such a paint should share the careful consideration which is accorded to other possible sources of sparking.

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Technical Associations and the War

IT is announced that the autumn meeting of the Institute of Metals, which is usually held in September, will be of a statutory character. It is planned to be held at the offices of the Institute on September 18, at 5 p.m., and only formal business will be transacted. No decision had been made at the time of writing regarding the date and time of the autumn meeting of the Iron and Steel Institute, which is also normally held in September. In the latter instance, too, it is probable that when the meeting is held only formal business will be transacted. Many of the technical papers that were to have been presented at these meetings have already been published, in whole or part in this journal, but two of these papers communicated to the Iron and Steel Institute are included in this issue.

Normally, at these autumn meetings, members of the respective institutes look forward to the infrequent opportunities they offer to renew friendships and to discuss problems and other matters of a more personal nature. The interchange of ideas, which usually takes place on these occasions, is one of the important features of institute annual meetings, and helps considerably in maintaining interest in the work of these technical associations. With the country at war and fighting for her very existence as a nation, the pleasure of attending an annual meeting must be sacrificed in view of the greater demands made upon members in this national emergency, but, while conditions do not permit the holding of normal annual meetings, it should be possible to maintain within the framework of each association means of contact, so that an interchange of ideas on new problems may continue.

This is not a new idea ; many associations, in fact, have standing committees of members to which problems encountered in industry can be submitted with a view to their solution. Much as this feature of a technical organisation's work may be desirable in peace time, the need is much greater in a national emergency such as we are experiencing now. Members are now mainly concerned with war work, and the conditions may often be very different from their accustomed activities, with the result that problems frequently arise, delay in the solution of which may easily hold up output. As a rule, the initiative and resourcefulness of the particular member will facilitate a solution, but, as the need for speed in production is urgent, it is necessary to find a solution which will contribute.

An example of this kind is presented by the Physical Society. To assist men who, in the present emergency, find themselves with technical problems in applied physics of which they do not happen to have had previous first-hand experience, it has been decided to extend the facilities of the Institute of Physics' panel of consultants. Through his medium inquirers are put in touch with those physicists most likely to be able to offer immediate practical suggestions in any particular case. In the first instance, the contact is quite informal ; subsequent arrangements are a matter of private agreement between those concerned. The subjects which can be dealt with cover all branches of physics, both pure and applied, including, for example, physical measurements and testing, the design and supply of scientific instruments for special purposes and the control of processes by physical means.

Many technical organisations contribute to the solution of problems arising under peace-time activities, and have increased their facilities during this emergency. Such organisations as the British Cast Iron Research Association, the British Non-Ferrous Metals Research Association, the various committees of the Iron and Steel Institute, and many other metallurgical associations collect and interchange knowledge of direct assistance to industry, and, by acting as clearing-houses in particular fields, supplement existing official and unofficial organisations. They contribute to the national effort by directing attention to existing solutions of difficulties which, while appearing new problems, may often be well known in other fields.

One difficulty that has been experienced by many is that of adhering strictly to existing specification standards. In the last issue particular reference was made to the need for more prudent use of our metal resources, that secondary and scrap aluminium could be applied to nearly 75% of the aluminium alloy products; to do so however, may involve the revision of certain standard specifications which specially call for virgin metal. In some instances trade organisations have been obliged, on account of urgency, to take steps to secure general agreement to contract out of existing British Standard requirements.

It has been appreciated by the British Standards Institution that the difficulties resulting from the war conditions render it impossible for manufacturers, in certain cases, to adhere strictly to all the requirements of British Standards. Problems of this character can now be overcome by making use of the British Standards Institution's War Emergency Procedure for any modification to a British Standard Specification to be issued, thus simplifying the position for all concerned. The machinery of this Institution has been adapted to enable War Emergency Revisions or the preparation of War Emergency Standards to be put through with a minimum of delay —in some cases, merely a matter of a few days.

This arrangement will be of distinct advantage to industry because it will ensure an adequate official check and the maintenance of the standard decided upon. In order to avoid confusion with the general British Standard specifications, the War Emergency Standards (or Revisions) are being issued in a distinctive form (on yellow paper), and it is also being made clear, wherever necessary, that such standards or revisions only apply to the home market, and not to the export trade, and can be modified again when peace conditions are restored. A number of such war revisions bringing about the necessary coordination have already been issued, and others are being prepared. This work is being done with the full co-operation of the appropriate Government Departments, who are frequently the users most directly concerned, and they welcome the issue of these War Emergency Standards where such are found necessary to expedite production.

It is not suggested that the technical associations are dormant during this war period ; many of them are making valuable contributions to the common cause, but, bearing in mind that a considerable number of the members of these organisations are now engaged on work with which they have not had previous first-hand experience, a more lively interest could be taken to ensure that every possible assistance be given to the solution of difficulties encountered in production.

Two Eminent British Scientists

BRITAIN mourns the loss of two of her celebrated sons by the death of Sir Oliver Joseph Lodge, on August 22, at the age of 89; and of Sir Joseph John Thomson, on August 30, at the age of 83. The work of these men was outstanding, and their contributions to progress will always be associated with the scientific discoveries of the period in which they lived.

Sir Oliver Lodge was born at Penkhull, Staffs., and, at the age of 14, left the Newport Grammar School to assist his father in the pottery trade. He became interested in science at the age of 16, and was subsequently nominated for a teacher's course at the Royal College of Science. Later he entered University College, London, and subsequently became lecturer in physics and chemistry at the Bedford College for Women, as well as University examiner. In 1880 he was appointed professor of physics in University College, Liverpool, and the 20 years during which he was at Liverpool were probably his most prolific period, and included his work on the ether drag and on the propagation of electric waves. Towards the end of 1900 he was offered the post of principal of the University of Birmingham, where administrative duties greatly curtailed his scientific studies. He was a Fellow of the Royal Society and received the Rumford Medal in 1898. He was knighted in 1902, and received the Albert Medal of the Royal Society of Arts for his work on wireless telegraphy. The Faraday Medal was awarded to him in 1932, but these are only a few of the many honours he received. He was Romanes lecturer at Oxford, in 1903, President of the British Association in 1913, and of the Society of Psychical Research from 1901 to 1904. He was the author of many scientific works.

Sir Joseph Thomson was born at Cheetham, Manchester, and it was intended that he should become an engineer, and, while waiting for a suitable opening, he was sent to Owen's College, but, after experiencing some difficulties, the idea of his becoming an apprentice to engineering was abandoned; by means of some small scholarships, however, he completed an engineering course. Concentrating on mathematics and physics, he obtained an entrance scholarship to Trinity College, Cambridge, and subsequently took the mathematical tripos examination, and came out second wrangler, and was Smith's prizeman. He was made a Fellow of Trinity in 1880. In 1884 he was elected a Fellow of the Royal Society, and later in the same year succeeded Lord Rayleigh as Cavendish Professor of Experimental Physics. Immediately afterwards, in conjunction with Threlfall, he began some experiments on the passage of electricity through gases; these opened a new field of research which he continued to study for the rest of his life. He was knighted in 1908, and a few years later received the Order of Merit. In 1918 he was appointed by the Crown to succeed the late Dr. Butler, as Master of Trinity College, when he resigned the Cavendish Professorship, and also the Professorship of Physics at the Royal Institution to which he had been appointed in 1905. Among the further honours conferred upon him was the Nobel Prize in Physics in 1906, and the Copley Medal of the Royal Society in 1914. Among the contributions to progress by Sir Joseph was the discovery that of the bodies into which the molecule split up, the one carrying negative electricity was quite different from an atom and, in particular that its mass was less than one-thousandth part of a hydrogen atom. To-day, these bodies are known as electrons. Sir Joseph has written many standard works, including Treatise on the Motion of Vortex Rings; Recent Researches in Electricity and Magnetism; Elements of the Mathematical Theory of Electricity and Magnetism.

MESSRS. GILMOURSMITH (ENGINEERING) LTD., 136, Renfield Street, Glasgow, C. 2, have been appointed to represent the interests of the Wellman Smith Owen Engineering Corporation in Scotland.

Forthcoming Meetings

INSTITUTE OF METALS.

BIRMINGHAM SECTION.

Sept. 24. "Bronze and Bronze Founders," by C. H. Desch, D.Sc., Ph.D., F.R.S.

Oct. 10. "Forging of Light Alloys," Open Discussion. At James' Hall, Memorial Institute, 6-30 p.m.

LONDON SECTION.

„ 10. Chairman's Address by J. Cartland, M.C., M.Sc., at Caxton Hall, Westminster, 7 p.m.

SCOTTISH SECTION.

„ 24. "Developments in Non-Ferrous Research," by F. Hudson. In rooms of Institution of Engineers and Shipbuilders in Scotland, at 7-30 p.m.

SHEFFIELD SECTION.

„ 11. "Developments in the Non-Ferrous Industries of Sheffield," by Ernest A. Smith, A.R.S.M. In the Mining Lecture Theatre, Department of Applied Science, The University, at 7-30 p.m.

MANCHESTER METALLURGICAL SOCIETY.

„ 16. "Intergranular Corrosion," by C. H. Desch, D.Sc., Ph.D., F.R.S. In the Engineers' Club, Albert Square, at 6-30 p.m.

The Aluminium-Tungsten Equilibrium Diagram

AN investigation design to cover the system aluminium-tungsten as completely as possible is described by W. D. Clark.* Alloys of aluminium and tungsten were prepared over the whole range 0–100% tungsten. It was found possible to melt and cast those containing up to 30% tungsten, while richer alloys were prepared by sintering compacts of tungsten and aluminium powders. A phase diagram is proposed which covers most of the system, and for the small region not elucidated, a configuration is suggested. During the course of this work, an apparatus was developed by which thermal analyses could be carried out on small specimens, and this is described.

There are three phases stable at room temperature in the range between the aluminium-rich α phase and the ϵ phase at 65% tungsten, and these decompose by successive peritectic reactions as the temperature is raised, giving ultimately liquid and ϵ. Alloys in the range 75 to 98% tungsten contain two phases and show three transformations of an isothermal nature in the range 1,350° to 1,300° C.; they decompose by a peritectic reaction at 1,650° C. The eutectic and peritectic reactions associated with these transformations all lie in the range 65 to 75% tungsten, and the details of this area could not be traced. The available facts have, however, been fitted into a self-consistent diagram.

Tungsten and aluminium are mutually soluble to the extent of about 2 per cent.

Personal

IT is announced that, in view of his many other interests, Mr. G. R. T. Taylor has resigned his seat on the Boards of Vickers Limited and English Steel Corporation Limited. He retains his directorship of Taylor Brothers and Co. Ltd., which company is a subsidiary of English Steel Corporation Limited.

MR. J. M. DUNCANSON has succeeded Mr. Ralph Alsop as Deputy Controller of Steel Supplies under the Ministry of Supply. He has been succeeded in the position of Assistant Controller by Mr. A. G. E. Briggs, who was formerly the Director of Alloys, Special Steel and Ferro-Alloys for the Control. Mr. Duncanson is a director of the Steel Company of Scotland, Ltd., deputy-chairman of R. Y. Pickering and Co. Ltd., and is also on the board of the Glasgow Railway and Engineering Co. Ltd. Mr. Alsop, who has been Deputy Controller in charge of steel supplies for the Ministry of Control since the outbreak of war, will resume his duties as general manager of the Consett Iron Company Ltd.

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*Jour. Inst. Metals, Aug., 1940, pp. 271-286.

The Importance of Time Studies on Autogenous Welding

By F. L. Meyenberg, M.I.Mech.E.

The increased complexity of modern production, together with greater competition in the world's markets, have favoured the use of scientific methods of production ; they have necessitated the careful study and analysis of the many variables encountered in the manufacture of many products, and in this article is discussed an investigation which had for its object the determination of production data for autogenous welded pipes. The results have been applied with much success and although conditions in different works will vary, the methods employed are of a fundamental character and cxn be used as a basis for time studies of similar work.

THE application of time-study methods to any particular section of industry demands great care ; a care rarely realised by the layman, and sometimes not even exercised by the specialist. Recent years, however, have seen great progress in the application of the results of time studies in industry which have not only increased production, but have contributed in some measure to a better understanding between workmen and management. The results of time studies have been applied to many products, and the investigations discussed in this article are concerned with the possibility of defining working times for autogenous welding on lines somewhat similar to those generally applied in other metal-working operations such as turning, sawing, grinding, etc. The original investigations were carried out about eight years ago by H. Rossié under the responsibility of the writer, but as they are of a fundamental nature and the problems considered are still in dispute, it is believed that they will have unusual interest.

It can be stated that the application of the time studies gave good results ; the times could be used with considerable success as a basis for fair piece-work wages. In addition, however, valuable improvements of the plant and of its use could be regarded as a consequence of these investigations. On the other hand, it should not be overlooked that the numerical results are valid only for the machinery under investigation, and not for machinery of a general character ; in principle the investigations can, of course, be applied as a guide in similar cases, but the figures cannot be applied to other plants because they probably work under different conditions.

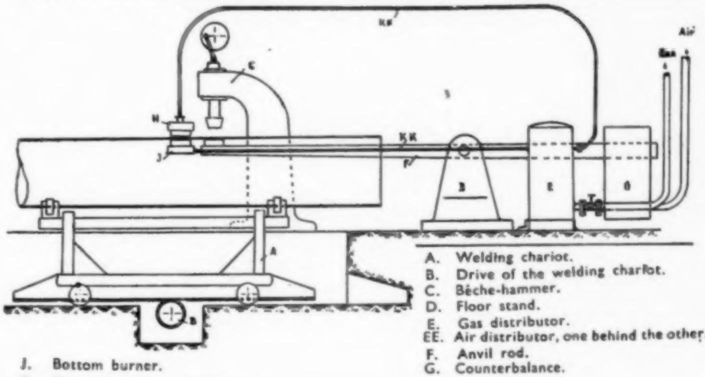
Description of Plant

Plates as delivered from the rolling mill were cut to size on a planing machine, and rolled to pipes on a plate-bending machine. They were welded on nine hammer welding machines (see Fig. 1) arranged adjacent to each other, and controlled by a common crane. The burner, shown in Fig. 2, had top and bottom parts of similar design arranged opposite to each other and parallel with the anvil rod. As soon as a portion of the pipe is sufficiently heated by the burner it is brought by the welding chariot under the pneumatic hammer, and welded. A steam-jet blower cools hammer and anvil rod during the heating turn, and removes the slag during the hammering of the welded seam. Two men are necessary for operating the machine, the welder who controls the machine and the "wrench man" who keeps the pipe in its correct place and moves it during the hammering.

The Production Programme

The pipes produced had internal diameters of about 16 to 32 in., thickness of plate 5 to 16 mm., and lengths of 23 to 26 ft. The welding machines were divided into three groups, A, B, and C, and the distribution of the various classes of pipes to the machines is shown by the following table :

Fig. 1.—Diagrammatic representation of a hammer welding machine.



A. Welding chariot.
B. Drive of the welding chariot.
C. Bèche-hammer.
D. Floor stand.
E. Gas distributor.
EE. Air distributor, one behind the other.
F. Anvil rod.
G. Counterbalance.
H. Top burner.
J. Bottom burner.
K. Gas air line (top burner).
KK. Gas air line (bottom burner).

Class No.	Internal Dia. In.	Thickness mm.	% of Total Production.	Produced by Machine No.	Machine Group.
1	16 to 24	5	8	5 and 6	*A* Light Machines
2	16 to 24	6	12		
3	16 to 24	7	20	2 and 8	
4	16 to 24	8	14	3 and 4	*B* Medium Machines
5	16 to 24	9	7		
6	24 to 32	8 to 9	5	7	
7	16 to 24	10 to 12	10		
8	24 to 32	10 to 12	4		
9	16 to 24	13 to 16	15	1 and 9	*C* Heavy Machines
10	24 to 32	13 to 16	5		

The investigation was limited to Nos. 1 to 5, 7 and 9—i.e., pipes of 16 to 24 in. internal diameter, which represented 86% of the total production, and of a material normally used for such pipes with a tensile strength of about 22 tons per sq. in.

Analysis of the Welding Process and the Necessary Working Time

Several heats are necessary for welding a pipe of a particular length. To find out the influence of the different variables on the welding process and the working-time, it is possible and useful to analyse this time as follows : The time for welding an individual piece of pipe during a single heat can be subdivided into :—[1]

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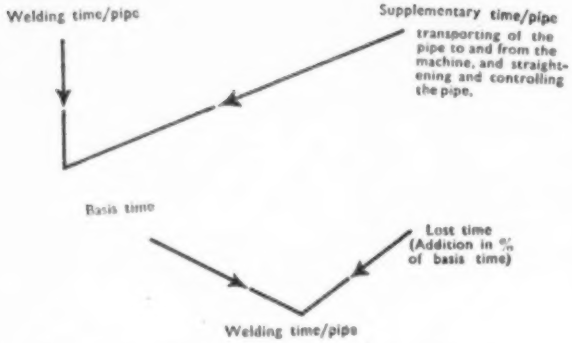
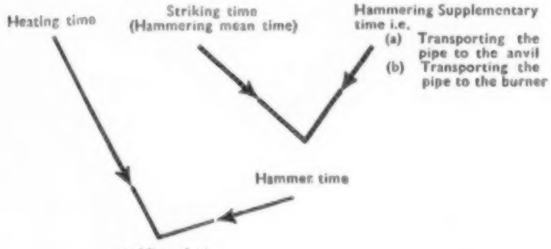
[1] The terms used are similar to those explained in *The New Management*, by H. T. Hildage, T. G. Marple and F. L. Meyenberg ; Macdonald and Evans, London, 1938.


Welding time/pipe
Supplementary time/pipe
transporting of the pipe to and from the machine, and straightening and controlling the pipe.
Basis time
Lost time
(Addition in % of basis time)
Welding time/pipe

Referring to the whole length of the pipe, it is convenient to use the sub-division :


Heating time
Striking time
(Hammering mean time)
Hammering Supplementary time i.e.
(a) Transporting the pipe to the anvil
(b) Transporting the pipe to the burner
Hammer time
Welding time

Limiting Factors and Their Influence on the Welding

A close investigation of these individual times and the kind of work to be done indicated that the limiting factors or variables which influence the welding process can be considered mainly as :

The length of the pipe.
The length of the burner.
The number of heats per pipe.
From these factors result—

$$\text{The feed per heat} = \frac{\text{length of pipe}}{\text{number of heats per pipe}} \text{ and}$$

$$\text{The rate of utilisation of the burner} = \frac{\text{feed per heat}}{\text{length of burner}}$$

The welding time is dependent chiefly on the length of the burner, but the length of the part that can be welded in one heat is limited in practice by the length which can be hammered while the material remains hot enough. The cooling rate increases with decreasing thickness of pipe, while the quality of the welding seam depends on the quality of the material used, and on the method of working which is again influenced by the length of burner. The effect of the burner is dependent chiefly on the feed and the rate of application. The length of heating time is affected by the quantity of gas used. In addition to the cost of special refractories in the burner, this quantity of gas is one of the main items of the process costs, and it is easily possible that with increasing burner effect the gas consumption increases so much that the final result is a decrease of economy.

These few remarks may be sufficient to indicate the limiting factors or variables which are related to each other in a rather complex way ; and it was the purpose of this investigation to determine numerically the mutual relations of these factors to such an extent that the method and the time of a special welding process could be determined with sufficient accuracy. It is not intended to give details of this investigation here, but rather to discuss the main features and to give the results.

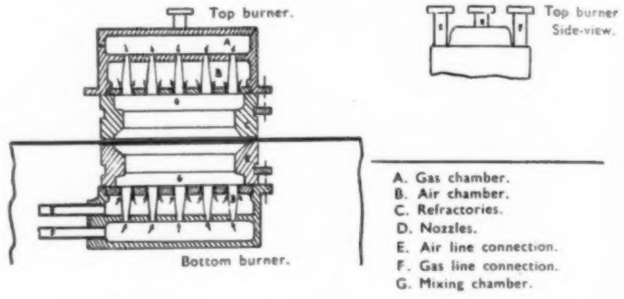
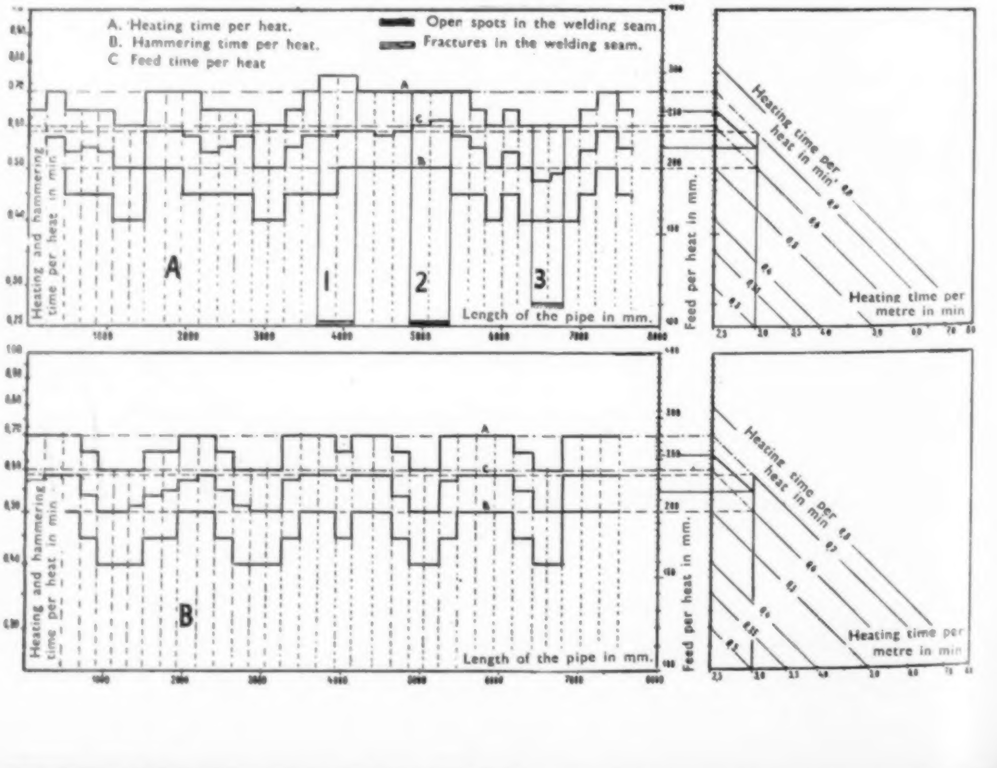

Top burner.
Top burner
Side-view.
A. Gas chamber.
B. Air chamber.
C. Refractories.
D. Nozzles.
E. Air line connection.
F. Gas line connection.
G. Mixing chamber.
Bottom burner.

Fig. 2.—Diagrammatic representation of an autogenous welding burner.

The Programme of the Investigation

As already mentioned, only pipes of 16 to 24 in. internal diameter and of 5 to 16 mm. thickness have been investigated, and the dimensions of the tested pipes have been taken so that conclusions could be easily drawn for any dimension between them. The investigations have been made with the usual burner of 10 in. length, and two burners of 13 to 15 in., respectively. Two men of an average capacity carried out the actual work for the experiments and the observations are always made on each man separately under the same working conditions, in order to be, as far as possible, independent of the human factor. About 10 pipes of each class and for each burner have been investigated and average figures formed from

Fig. 3.—Production diagram of the burner about 10 in. in length for the class 16 to 24 in. diameter and 7 mm. thickness.



the reliable results. One machine of each of the three groups is used for the tests. The course of the work and the individual times were investigated by time studies carried out in the usual manner, but as carefully as possible; the quantity of gas has been measured by the orifice method. Tensile tests of the original plates as well as of the welding seam have been taken of each investigated pipe, in order to exclude mistakes arising from bad material; also chemical analyses of each melt—i.e., for every 10 to 15 pipes belonging to one melt, have been carried out. The finished pipes have been carefully inspected, and all welding defects accurately recorded. Finally, the pipes were subjected to the usual tests under hydraulic pressure.

Evaluation of the Results of the Investigation

The strong connection between the method of welding and the welding defects could be demonstrated clearly by the use of recording instruments which assisted, to a large extent, the usual time studies. An example is given in Fig. 3, the left parts of which show the production diagrams of two pipes of exactly the same kind, but the upper one with various defects in the welding seam, and the lower sound throughout. The reason for the defects can be taken directly from the diagram: either the heating was too long and the material burned, shown at 1, or the feed was too high, and caused open spots in the welding seam, shown at 2, or the feed was too low and the material burned by repeated heating which broke when hammered, as shown at 3.

Fig. 4.—Changes in costs, when using burners of various lengths for pipes of different thickness in relation to the cost when using the 10-in. burner.

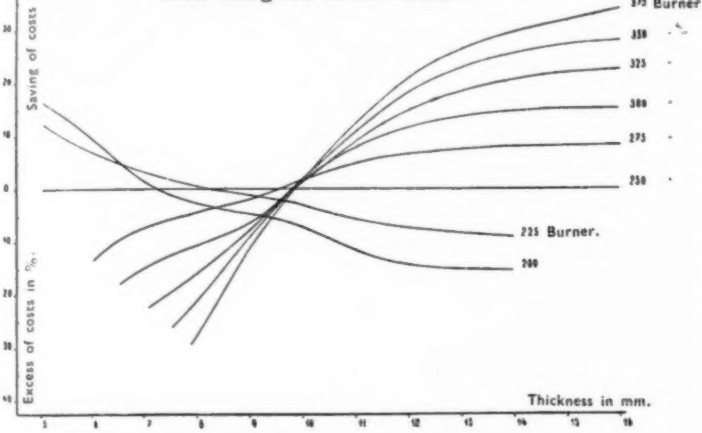
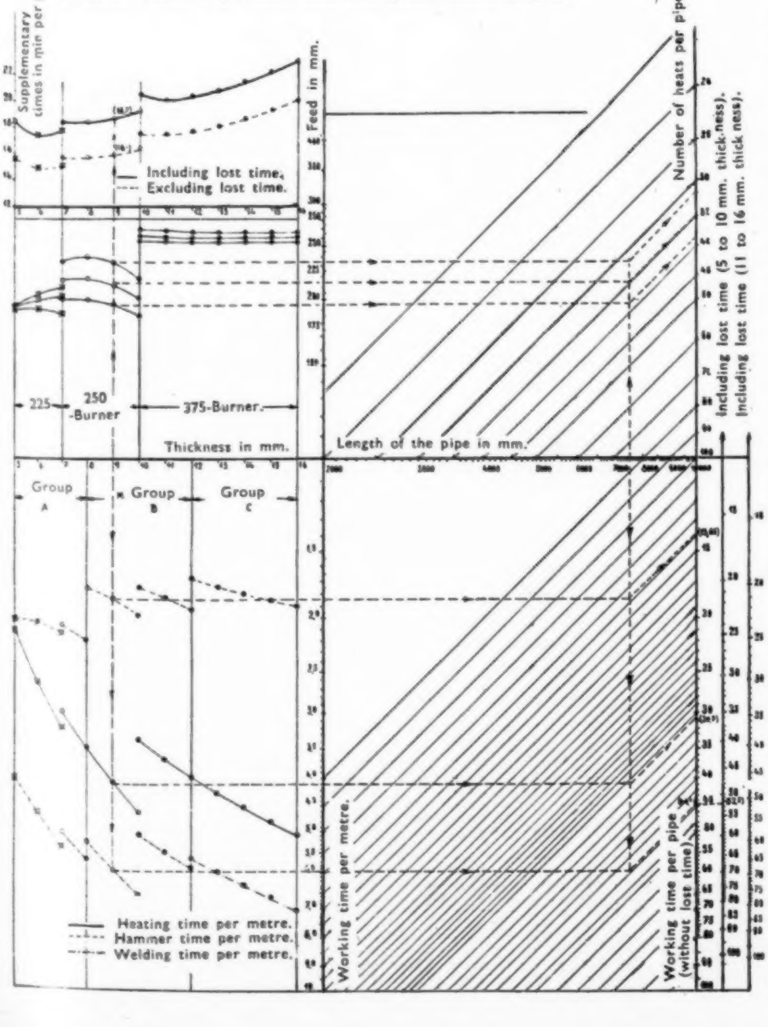


Fig. 5.—Nomogram for determining the course of the autogenous welding process and fair piece-work wages.



The right parts of this illustration are graphs for finding the heating time per metre from the feed and the heating time per heat; and it is clear that the heating time per metre is practically constant as long as the welder uses feeds within reasonable limits—a fact which is confirmed throughout all these investigations. This "regulating sphere" is different for different burners and different thicknesses of the pipes, and had to be determined for all important cases in practice.

Based on the experience obtained by these investigations the correct feeds, heating times and hammering times, as well as their connections with each other could be arranged in corresponding graphs, whereby the experimental results for the hammering time were verified by a comparison with the results of a theory of the hammering process published by an independent investigator.

In a similar manner supplementary and lost times have been determined, and the influence of the length of the burner on these times was especially investigated. Whilst such an influence could to some extent be stated on supplementary times, the lost times were practically independent and could be taken as an addition of 17% to the basis time for pipes of 16 to 24 in. internal diameter and 5 to 10 mm. thickness, and of 15% for the same pipes, but of 11 to 16 mm. thickness. This includes an addition for recreation of 5% which was found necessary in view of the special difficulties under which the men had to work, as, for instance, heat, noise, continuous attention.

As was to be expected, it was found that the consumption of gas per unit of time increased proportionately with the length of the burner, but this was lessened to some extent for thicknesses under about 12 mm. by the smaller degree of efficiency of the longer burners. It was, therefore, necessary to carry out a separate investigation in this direction.

Determination of the Economical Length of the Burner for each Pipe Class

The wages and the costs of the gas consumed form the most important items of the proportional part of the total costs. The other items are either fixed costs or variable to such a small extent that they can be neglected for the comparison in question. By using the results

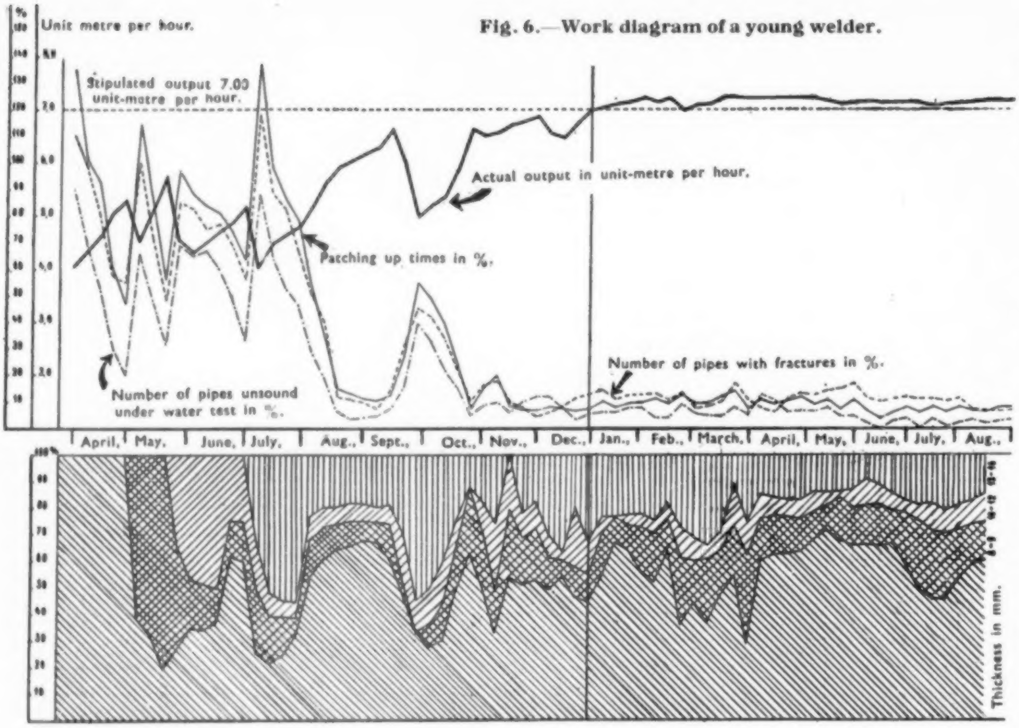


Fig. 6.—Work diagram of a young welder.

of the tests and graphic methods of extra and interpolation, for burners of lengths of 8 to 15 in. and pipes of 5 to 16 mm. thickness, the heating times per metre, the supplementary times per pipe, the feed per heat, and the hammering time per metre could be determined, and by combining these graphs and taking the working conditions of the burner of a length of 10 in. as basis, a diagram, Fig. 4, could be developed which shows the changes of costs when using burners of various lengths for pipes of different thickness.

As a result of this subsidiary investigation it was decided to use three different burners:

For thickness 5 to 6 mm. a burner of 225 mm. (about 9 in.) long.
,, ,, 7 to 9 ,, ,, 250 ,, (,, 10 ,,) ,,
,, ,, 10 to 16 ,, ,, 375 ,, (,, 15 ,,) ,,

The diagram seems to indicate that even a burner of a greater length than 15 in. should be used, but if that were done, the radiant heat would be too great for the workmen, and also other production difficulties would arise to interfere with the quality of welding.

Nomogram for Determining the Course of the Welding Process and Fair Piece-Work Wages

The relations between the limiting factors found by these investigations can be further used in developing the nomogram Fig. 5, which in each case enables the best working conditions and the resulting working time. This can best be shown by following up the draw-in example: A pipe of 20 to 24 in. internal diameter, 9 mm. thickness and 25 ft. in length is to be welded. A burner of 250 mm. (about 10 in.) long is used, and a machine of group B employed. The feed will be chosen between 195 and 235 mm (about 7¾ and 9¼ in.), and the number of heats between 39 and 32. This will result in the following times:

Heating time per metre = 4·1 min.—i.e., per pipe = 30.7 min.
Average hammer time per metre = 1·85 min.—i.e., per pipe = 13·85.
Average welding time per metre = 5·95 min.—i.e., per pipe = 44·55 min.

Supplementary time	= 16 min.
Total working time, excluding lost time	= 60·55 ,,
Welding time, including lost time	= 52·2 ,,
Supplementary time, including lost time	= 18·7 ,,
Total working time, including lost time	= 70·9 ,,

It is not necessary to point out in this connection the advantages which can result from a correct instruction of the course of production and the determination of fair working times as basis of piece-work wages—this was discussed by the author in an earlier issue,[2] but it may be of interest to see how these investigations have resulted in a system of production control, and what improvements could be obtained.

The Production Control

When the working times for various classes of pipe have been stipulated, a comparison can be made between the work actually done and what ought to be done—i.e., output can be controlled. But that alone is not sufficient; it is necessary to find measures for the quality of the welding of the pipes and as the welding depends to a great extent on the ability and care of the man doing the job, this demand is identical with the application of a control system which permits the continuous supervision of the work of each single welder. For this purpose an elaborate control-plan has been developed which seems to be rather complicated and would probably have been uneconomical, had not the Hollerith system[3] used for other purposes in the works in question proved a great help. The whole work of punching, sorting and tabulating the cards, as a basis of the statistics described below, took only about half an hour's work of one set of Hollerith machines.

To obtain the necessary figures of output, rejects, reasons of defects, etc., care was taken that no new forms were introduced into the shop, but the usual vouchers for wages, day work as well as piece-work, were so formed that they contained all fundamental figures if completed properly.

The welding work was done under the supervision of a foreman who induced the men to repair defective pipes without special payment as soon as he found out that defects had slipped in; he was also responsible for the correctness of the corresponding records. A second control was effected by a gang of men who were especially concerned with surface defects, and a detailed record was made for which the foreman of this gang was responsible. The finished pipes were tested under hydraulic pressure, and a third record resulted. Pipes found defective during the second and the third control were repaired and patched up by a separate gang of men in order to avoid transport reversals, which would disturb the flow of the sound pipes. A special record was prepared concerning this repair work. All these records were used to build up separate reports of the output for day and night shifts with the number of rejected pipes separated according to the various kinds of defects, etc., and all reports provided the various data for each class of pipes separately. But as the number of metres welded in one class cannot be compared with those welded in another class a "unit metre" has been taken as standard—i.e., the metre of a pipe of 500 mm. (about 20 in.) internal diameter, 8 mm. thickness, and 7,500 mm. (about 25 ft.) length, and the results of all other classes were converted into "unit metres" by means of equivalent figures.

In order to find out the reasons for high or low output, good or poor quality of welding, etc., in one shift against another, similar data were prepared for each welder, and then shown in graphs and Fig. 6 gives an example. It shows the work diagram of a young welder over a period of nearly 1½ years—i.e., from the day of starting work with comparatively small output and a high number of defective pipes, especially when a change of the class of pipes takes place; through a period beginning after about five months on similar work when the output is nearly as high as it ought to be, but a change of classes of greater thickness immediately results in a decrease of output and quality; up to equalised work and good welding of all classes with few defects at the end of the eighth month. This man, therefore, became a good welder in the comparatively short time of nine months.

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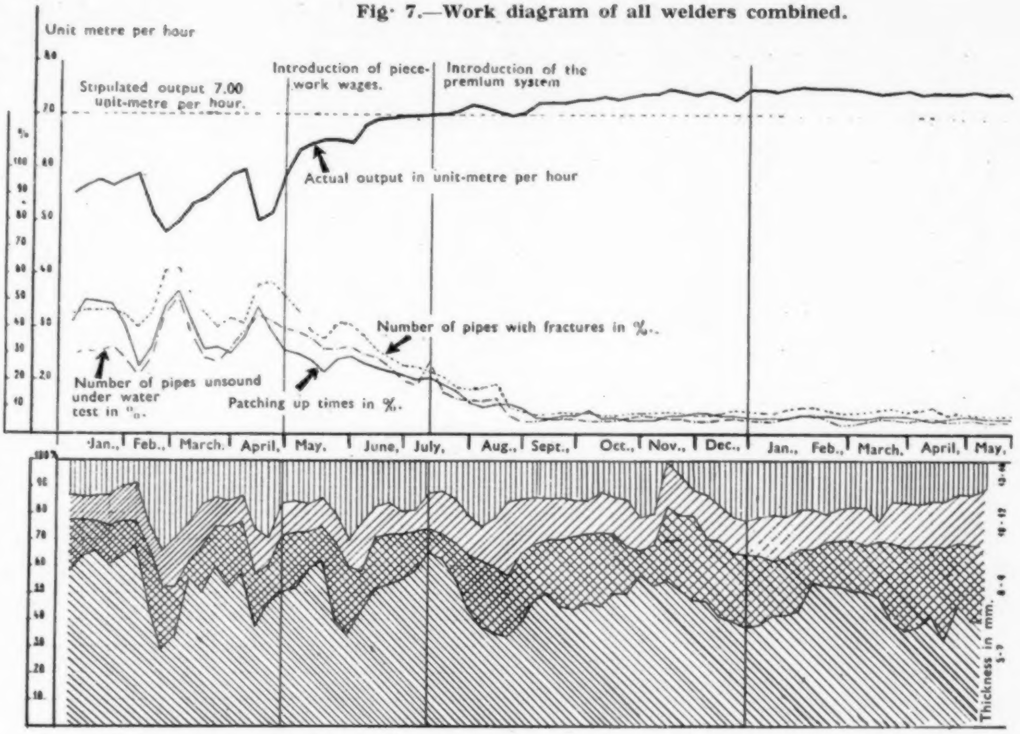
[2] *Metallurgia*, January, 1939, pp. 101 to 104.
[3] *Metallurgia*, June, 1939, pp. 59 to 62.

Fig· 7.—Work diagram of all welders combined.



The work diagram of all welders combined, as shown on Fig. 7, gives simultaneously the total result of this whole investigation. It should be self-explanatory, and each addition would perhaps only diminish the impression that the research work accomplished in this case has not been in vain, since the output has been increased from 5·5 to 7·5 unit metres per hour—i.e., 36·5%; the patching hours went down from 40% to 6%, the number of pipes with fractures from 50% to 8%, and the number of pipes failing in the hydraulic test reduced from 35% to 5%.

Finally, it may be of interest that, in addition to the piece-work system as recompense for increased output, these results have been obtained by applying a premium system as a reward for improved quality. The actual patching times as percentages of the stipulated total working times have been used as measures of quality, and Fig 7, but particularly the production diagrams of individual welders, who have been connected with this kind of work longer than the man referred to in Fig. 6, show the favourable influence of this measure.

British Standards Specifications

Steel Conduits and Fittings

THE British Standards Institution has just issued the revision of B.S. 31-1933 for Steel Conduits and Fittings for Electrical Wiring. This revision was undertaken principally with the view to clarifying the position of the lugs relative to the spout outlets in small circular boxes and the table giving the dimensions of the entry bushes has also been slightly amended.

Tests for Laboratory Porcelain

THE British Standards Institution has just issued a British Standard, No. 912, for Tests for Laboratory Porcelain. The tests included are: Appearance, shape, weight, etc., porosity of body and imperfections in glaze (dye test), resistance to heat and sudden change of temperature, constancy of weight and resistance of glaze to high temperature and resistance of glaze to acid and alkali.

The tests thus provided should be helpful both to the manufacturer and the user; to the former in helping him to improve his product, and to the latter in assisting him to avoid the disappointment of porcelain ware being found defective in actual use, although its defects were not previously evident.

Several tests are based on those adopted by the sub-committee on porcelain of the Glass Research Committee of the Institute of Chemistry and published in 1920. One test, however, that of the resistance to heating and cooling, is entirely new, it being an accelerated test, having no counterpart in laboratory practice. It is considered, however, that it offers the manufacturer a consistent, rapid, and convenient control of the quality both of his standard material and of any experimental material he may be investigating. The porcelain industry in this country is developing rapidly, and it is hoped that the publication of this British Standard will assist in the further improvement of the quality of British laboratory porcelain ware.

Copies of the above standards may be obtained from the British Standards Institution (Publication Department), 28, Victoria Street, London, S.W. 1, price 2s. 3d. each post free.

Ferro-Nickel from Open-Hearth Furnaces

A METHOD for obtaining ferro-nickel in open-hearth furnaces has been developed by Mr. T. Lukavchenko, an engineer at the Institute of Research in ferrous metals in the Urals. After much experiment in the laboratory and then on a semi-industrial scale at the Nizhne-Saldinsk Metallurgical Works, Mr. Lukavchenko obtained ferro-nickel, with a nickel content up to 40%, in an open-hearth furnace. The alloy is claimed to be eminently suited to the manufacture of nickel steel, and by using this method it is possible to organise the production of ferro-nickel at any steel works, having open-hearth furnaces, without additional plant outlay. The raw materials used in the process are nickel ores, fluxes, and small coke waste.

Correspondence

Alloys Containing Chromium and Boron

The Editor, Metallurgia.

Sir,—In your July issue Mr. L. Sanderson mentions in an article the use of a new hard metal—chromium boride. He states that this material is claimed to be harder than the better known carbides. My interest is mainly academic, but during the last few months I have been interested in the physical side of tungsten carbide manufacture, and I would be glad if you could put me in touch with any literature relating to the preparation and properties of chromium boride.—Yours faithfully,

K. G. L.

Quinton, Birmingham,
August 9, 1940.

Probably the most useful information about these new alloys is obtainable from patents which have been taken out; these indicate that the simultaneous presence of boron and chromium in many alloys has the effect of improving the wearing qualities, while in many cases facilitating mechanical and thermal treatment. They may be conveniently classified into :—(*a*) Chromium borides; (*b*) ferrous alloys; and (*c*) non-ferrous alloys.

(*a*) *Chromium Borides.*—Aluminothermic treatment of a mixture of chromium and boron oxides was used by Cole and Edmonds[1] in the production of borides corresponding to CrB_2, CrB and Cr_3B_2. A mixture containing these borides together with some metallic chromium, boron and aluminium was thus obtained by igniting a mass comprising 46.25% CrO_3, 16·25% B_2O_3 and 37·5% aluminium powder. In the course of the resultant fusion (when a temperature of 4,000° C. is said to be developed) the conglomerate of chromium borides and free metals flows to the bottom of the crucible. For some purposes the unrefined boride mass (known as Colmonoy) remaining after the melt has been crushed and washed (a typical elementary composition of which might be 63% chromium, 27% boron, and 10% aluminium) is quite satisfactory. What are known as Colmonoy crystals, the residue of 75–80% remaining after the crude melt has been digested for many hours with hydrochloric acid, consist essentially of the chromium borides and are used in the manufacture of cutting tools. A tough and low-melting tool alloy is made from 12–16% Colmonoy crystals, 12–16% tungsten powder, and 68–76% iron powder; a very hard and high-melting tool might contain 75–90% Colmonoy crystals and 10–25% nickel. In these alloys the cutting strength is chiefly attributed to the compound CrB_2, which is assumed to be uniformly distributed through a matrix formed when the remaining alloy metals (nickel, tungsten, etc.) combine with the other components present. Alloys containing a preponderating amount of Colmonoy crystals are economical when used in the surfacing of steel tools owing to their low density. Weight for weight, they cover three times as much surface as tungsten carbide.

Pure chromium diboride, CrB_2, is extracted from the residue of hydrochloric acid digestion by boiling for a considerable time with sulphuric acid (s.g. 1·3). It has been described as a brown substance of tetrahedral crystalline structure, s.g. 4·2–4·55 and with a hardness of 8·5 or higher on Mohr's scale. It is insoluble in hydrochloric and sulphuric acids, and in potassium hydroxide, but dissolves in hydrofluoric acid and also becomes soluble after fusion with sodium peroxide. The crystals do not fuse at 1,350° C., but can be fused in the electric arc. Granules of CrB_2 can be used as a loose abrasive for grinding and polishing surfaces, or make up into abrasive wheels with the aid of bonding agents (rubber, shellac, bakelite, etc.). The crystals may also be incorporated into the body or surface of metals by various methods.

(*b*) Ferrous Alloys.—Small percentages of boron, chromium and other metals find application in the manufacture of high-speed steel tool alloys. Carbon may be omitted from these alloys, and they are amenable to thermal treatment, if boron, chromium and vanadium are present in addition to tungsten or molybdenum. A typical cutting alloy on these lines, according to A. G. de Golyer[2] contains 9–20% tungsten, 0·25–2·15% boron, 1·5% chromium, 0·5–4% vanadium, less than 1% manganese and silicon and the balance iron. The same inventor has found[3] that a satisfactory molybdenum high-speed steel is obtainable in the complete absence of tungsten when boron and zirconium (in addition to chromium, etc.) are present—e.g., 0·2–2·5% boron, 2–6% chromium, 0·25–5% zirconium, 6–16% molybdenum, 0·5–3% vanadium, and 0·1–0·9 carbon. These alloy elements prevent the formation of soft decarburised layers and are claimed to yield a molybdenum steel with a higher cutting efficiency than previous tungsten steels. The new steels can be cast, forged and welded, but are preferably used in the wrought condition.

Tungsten steels alloyed with a little chromium and boron appear to be unusually resistant to the abrasive effect of siliceous particles. A convenient raw material for these alloys[4] is tungsten carbide steel scrap. In addition to iron the alloys may contain 1–15% carbon, 14–18% tungsten, 0·5–2% boron, and 5–6% chromium. Cast tubes (the boron improves the fluidity of the alloy during casting), give good service as sand-blasting nozzles and as nozzles for leading abrasive mud through well drills in deep well operations.

(*c*) *Non-ferrous Alloys.*—Boron enters into the composition of a number of denture casting alloys in which the chief components are chromium, nickel and/or cobalt, according to Grossman.[5] Other ingredients are manganese or silicon (which function as deoxidising agents) and molybdenum or tungsten (strengthening agents). The purpose of the boron is to act as a safeguard against oxidation of the chromium alloy in course of remelting and casting to form dentures by the centrifugal process. Boron is believed to be the only alloy component which forms a relatively low-melting slag on oxidation and so protects the chromium alloy against direct contact with oxidising agents. A proportion of 5% boron is recommended—e.g., 25% chromium, 33% nickel, 36% cobalt, 1% manganese, and 5% boron; or 25% chromium, 69% cobalt, 1% manganese, and 5% boron.

Hand Carbon Arc Welding

Automatic carbon arc welding is now generally accepted in a number of industries as the most suitable welding process for dealing with repetition work involving a succession of long runs. The carbon arc is essentially a fusion-welding process, primarily suitable for edge and corner joints in mild steel. High welding speeds are obtained, and in light sheet-metal work no filler wire is necessary; in addition, the carbon consumption is very low, resulting in a most economical and simple method of fusion welding.

There are, however, a large number of applications suitable for carbon arc welding, in which, due to high initial cost or for other reasons, the automatic or semi-automatic method cannot be employed. This applies particularly to light sheet-metal work involving short or irregular runs in medium quantities.

To meet the requirements of this type of work, Siemens-Schuckert (Great Britain), Ltd., have developed a new carbon arc torch for hand welding. Two sizes are available, for currents up to 80 amp. and 160 amp., and suitable for welding material from 20 s.w.g. to $\frac{3}{16}$in. Any size of carbon up to $\frac{1}{4}$ in. diameter can be used as required, without making any adjustment to the torch. A powerful blow-coil incorporated in the carbon holder ensures a steady arc, this being necessary in order to obtain good consistent results. Special attention has been paid to the question of fatigue, and in addition to reducing the weight to the practicable minimum, the balance has been carefully adjusted to minimise strain on the operator.

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[1] U.S. Patent, 2,088,838.

[2] U.S. Patents 2,135,494-5.

[3] U.S. Patents 2,137,109-10.

[4] U.S. Patent 2,160,290 of Hughes Tool Company.

[5] U.S. Patents 2,155,047 and 2,165,849.

An Accelerated Spray Test for the Determination of the Relative Corrodibility of Ferrous Materials*

By T. Swinden, D.Met. and W. W. Stevenson, A.I.C.

A method of automatic accelerated spray testing is described, in which specimens, on an endless belt, complete a cycle of treatment consisting of spraying, followed by drying in air and in a warm chamber. Comparative results of long-period field tests and spray tests are given for 14 irons and steels of the low-alloy constructional type. It is suggested that the results obtained with the sulphuric acid/sodium chloride solution show promise of the spray method being used as the basis of a satisfactory short-time laboratory corrosion test.

THE desirability of having a reliable laboratory method for the rapid evaluation of the relative atmospheric corrodibility of irons and low-alloy steels of the constructional type has long been considered by many workers in the field of corrosion research. The position in regard to relative corrodibility under conditions of immersion has been clarified by the excellent work by Bengough and Wormwell.[1] It is generally accepted, however, that immersion tests do not produce the same order of merit as is obtained in long-period exposure to the atmosphere.

The conditions of atmospheric corrosion entail the wetting of steel by weak acid liquids (particularly in industrial atmospheres) and subsequent evaporation of the liquids; condensation of liquids and evaporation, with changes of temperature; partial removal by mechanical means of the corrosion product, and so on. The obvious experimental procedure is suggested, therefore, of attempting to reproduce in the laboratory a cycle of atmospheric changes involving wetting and drying, heating and cooling, in which the corrosion is of the oxygen-absorption type. From the wide differences in results obtained by atmospheric exposure and by immersion in acid, the authors consider that hydrogen evolution plays no major part in atmospheric corrosion. Since the supply of oxygen will be facilitated if the corrosive medium is in the form of fine droplets, it is desirable to wet the specimens with a fine spray. Also, as the size of the droplets decreases it should be possible to increase the acidity of the solution without unduly introducing the effect of hydrogen evolution. This is in line with the views of Evans.[2]

Earlier work on spray tests had been carried out by Evans and Britton,[3] Hatfield and Shirley, [4, 5] Hudson[6] and Schroeder.[7] Using a simple spraying procedure, twice a day for 23 days, Evans and Britton[3] concluded that it seemed possible to obtain, in laboratory spray tests, an order of merit which was a reliable indicator of the "liability to *commence* rusting" under typical service conditions. They suggested $N/100$ sulphuric acid as the spray liquid for urban atmospheres, and either sea water or 3·5% sodium chloride solution for marine atmospheres. They also stated the view that the order of merit for long-time atmospheric exposure was unlikely to be the same as that obtained in short-time laboratory spray tests, at the same time indicating the possibility that more intensive spraying with acid, of the order of 10 times daily with intervening drying periods, might within a reasonable time reveal the long-period order. Hatfield and Shirley[4] sprayed their specimens at constant spray pressure, once daily for 36 days, using two different types of spray liquid, (*a*) 3% sodium chloride solution and (*b*) $N/100$ sulphuric acid. Their results showed that some materials in the salt-spray tests corresponded quite well with the short-time field tests, whilst other materials were not so good; the agreement of the acid tests with the short-time field tests was less satisfactory than that for the salt spray tests. Hatfield and Shirley[5] supplemented their work with one-year field tests. They found good agreement between the salt-spray and the short-time (36-day) field tests for the more resistant steels, but the less resistant steels (of the type dealt with in the present paper) gave different results. For these steels better correspondence was found between the salt-spray and the long-time (one-year) field tests, but, anomalies existed. For instance, the salt-spray tests failed to bring out the beneficial effect of 0·45% of copper in mild steel. The acid-spray tests did show this, but, on the other hand, the general correspondence between the acid-spray and the field tests was still less satisfactory. Hudson[6] used a fixed spray device, and sprayed his specimens twice daily with $N/100$ sulphuric acid for 20 days. The correlation between Hudson's spray tests and short-time field tests supported the view of Evans and Britton[3] that the intermittent spray test gives the short-period order of merit of the materials tested. Hudson also commented on the fact that better agreement between the two types of test was obtained in the case of ground specimens than of pickled ones, suggesting that this was possibly due to the behaviour of the copper in the copper-bearing steels during pickling.

Schroeder's[7] work is of special interest, as he rendered the spraying automatic, by mounting the specimens on a belt, driven by motor and reduction gearing, thereby bringing the specimens, at fixed intervals, into the operation zone of the sprays. The first spray apparatus constructed at Stocksbridge (described below) actually contained a few of the parts of Schroeder's equipment. Schroeder used sprays consisting of (*a*) $N/100$ sulphuric acid, and (*b*) a mixed-salt solution containing 16 g. of ammonium sulphate and 4 g. of ammonium chloride per litre, and he also describes one test in which, in addition to spraying, downpour and sunshine were simulated, by douching the specimens periodically with water, followed by exposure to a heating element. In this test he obtained accelerated corrosion, as compared with tests when spraying only was carried out, and also a marked improvement in correlation with the short-period field test.

A further effort to correlate spray tests with field tests was made by Hatfield and Shirley, Swinden and Stevenson, and Hudson and Banfield,[8] who carried out spray tests at Sheffield, Stocksbridge and Birmingham, and exposure tests at Sheffield and Stocksbridge, on eight low-alloy structural steels in connection with Part III of the Corrosion Committee's experimental programme. Two types of spray liquid were used, $N/100$ sulphuric acid and the mixed-salt solution previously used by Schroeder (*vide supra*). Comparing the spray-test results with short-period (four-week) and long-period (one-year) field tests, no correlation was found between the results of the intermittent spray tests with the mixed-salt solution and either series of field tests; the spray tests with $N/100$ sulphuric acid were only slightly more satisfactory. Excellent agreement was found in the different series of long-period field tests, but there was no satisfactory correlation between the different laboratories, either in the spray tests or in the short-period field tests. The results of the short-period field tests agreed better with the long-period field tests than did the results of either series of spray tests. In this investigation the spray method in each of the three laboratories was of the static type previously investigated by Hatfield and Shirley[4, 5] and by Hudson.[6]

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* Communication from the Central Research Department, The United Steel Companies, Ltd., for presentation at the Autumn General Meeting, Iron and Steel Institute, 1940.

REFERENCES.

[1] G. D. Bengough and F. Wormwell: Third Report of the Corrosion Committee, p. 123, Iron and Steel Institute, 1935, *Special Report No.* 8: G. D. Bengough and F. Wormwell: Fourth Report of the Corrosion Committee, p. 213, Iron and Steel Institute, 1936, *Special Report No.* 13.

[2] U. R. Evans: "Metallic Corrosion, Passivity and Protection," p. 654. London, 1937: E. Arnold and Co., Ltd.

[3] U. R. Evans and S. C. Britton: First Report of the Corrosion Committee, p. 139, Iron and Steel Institute, 1931, *Special Report No.* 1.

[4] W. H. Hatfield and H. T. Shirley: First Report of the Corrosion Committee, p. 156, Iron and Steel Institute, 1931, *Special Report No.* 1.

[5] W. H. Hatfield and H. T. Shirley: Second Report of the Corrosion Committee, p. 197, Iron and Steel Institute, 1934, *Special Report No.* 5.

[6] J. C. Hudson: First Report of the Corrosion Committee, p. 211, Iron and Steel Institute, 1931, *Special Report No.* 1.

[7] W. A. W. Schroeder: Second Report of the Corrosion Committee, p.185, Iron and Steel Institute, 1934, *Special Report No.* 5.

As stated in the Fifth Report of the Corrosion Committee,[9] the authors proceeded to modify and extend Schroeder's automatic spraying apparatus, so that larger specimens 4 × 2 in., could be accommodated. All operations were standardised as far as possible, in an effort to ensure equal treatment for all specimens. The principles observed were those of Schroeder's douching test in that the cycle of operations consisted of intermittent spraying followed by exposure to a heating chamber; also the specimens were given a daily douching with water, under standardized conditions, for the purpose of detaching loose rust from the surface.

The Test Materials

For the spray tests, a series of 14 Corrosion Committee materials was selected, 11 of which had been the subject of previous field tests (and, in the case of seven materials, previous spray tests[8]), and three of which were new materials—Aston-Byers iron, Swedish iron and carbonyl iron. The analyses of the materials are given in Table I.

TABLE I.
Analyses of the Steels and Irons Tested.

Material.	C. %	Mn.%	Si.%	S. %	P. %	Cr. %	Cu.%
Carbonyl iron	0·02	Nil	Trace	Nil	Nil	Nil	Trace
Swedish Lancashire-iron	0·03	Nil	0·02	0·008	0·054	Nil	Trace
Staffordshire wrought iron	0·03	0·02	0·14	0·19	0·23	Trace	0·04
Aston-Byers iron	0·02	0·02	0·12	0·007	0·14	Trace	Trace
Ingot iron	0·03	0·03	0·03	0·036	0·009	Nil	0·04
Rail steel	0·53	0·72	0·30	0·037	0·043	iNl	0·01^{5}
XK steel	0·21	0·58	0·10	0·032	0·042	0·09	0·02
ZK steel	0·23	0·60	0·11	0·026	0·035	0·06	0·50
K steel	0·27	0·59	0·12	0·031	0·042	0·98	0·02
L steel	0·26	0·60	0·13	0·026	0·038	0·59	0·47
N steel	0·28	0·83	0·13	0·038	0·043	0·92	0·47
O steel	0·24	1·53	0·34	0·035	0·036	0·03	0·52
X2 steel	0·23	0·59	0·01	0·026	0·031	0·06	0·02
Z steel	0·21	0·62	0·03	0·036	0·039	Nil	0·52

In all the spray tests and field tests the results of which are given in this paper, specimens approximately 4 × 2 × ⅛ in. (weighing approximately 125 g.) were used with their surface ground on a linisher belt, grade 80.

The Apparatus and Method

The equipment used for the spray tests has undergone a slow process of evolution in the laboratory, and it is therefore desirable to give detailed descriptions both of the original form and of the latest form now in use. The original apparatus is shown in Fig. 1, and its operation is described as follows:

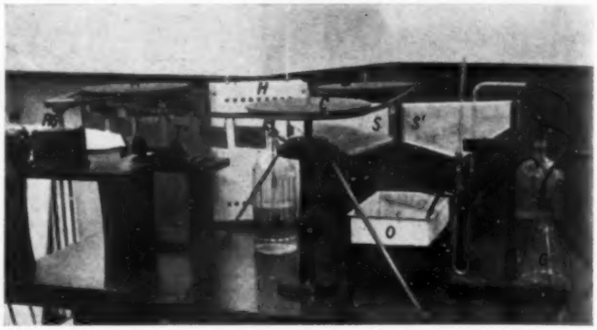

Fig. 1.—The original apparatus for accelerated spray test.

The specimens (maximum number 20, of size 4 × 2 in.) are attached to a travelling belt by means of short lengths of cord passing through holes in the specimens, and hanging from hooks on the belt. The latter moves round the 12-in. dia. pulleys A, B and C. The pulley A has a belt-drive from the motor M and reduction gearing RG. The belt on which the specimens are hung moves round the three pulleys at a speed of one complete revolution per 7 min., and during each revolution the specimens are subjected to the following treatments:

Spraying.—Passing between the spray-shields, S, S′ they are sprayed on both sides with the spray solution. This spray is obtained by means of compressed air (from a blower) passing from the gas reservoir G to the two solution reservoirs, R, R′. The latter are Winchester quart bottles fitted with bakelite spray nozzles capable of delivering a uniform spray at a distance of 12 in. from the nozzle. The compressed-air pressure is measured by the manometer P, and is gradually increased as the level of the solution in the spray reservoirs falls. Spray is allowed to impinge on the specimens over only ½ in. of their length at a given moment (i.e., the specimens are sprayed for a period of about 2 secs.). Liquid not impinging on a specimen falls into the sump O, or into the sumps of the spray shields, S, S′, whence it is drained into O.

Drying.—After spraying, the specimens pass round the pulleys C and A, during which time they are air-dried to some extent, after which they pass through the heated chamber H. This is a metal box, ventilated at the top and bottom and heated by means of two carbon-filament lamps working at a voltage which will raise the temperature of the air passing through the chamber to 40° C. In passing through this chamber, during a period of about ¾ min., the specimens become quite dry on the surface, but are not heated unduly.

After passing through the heating chamber, the specimens travel round the pulley B back to the sprays and so on.

Douching.—The specimens pass through the cycle of treatments 60 times per day (approximately 7 hours), five days per week for four weeks. On the second and subsequent days they are douched with distilled water, and allowed to dry thoroughly before spraying is commenced.

The daily douching is carried out by a standardised procedure: Distilled water (110 ml.) is placed in a tap funnel, and is allowed to run, with an initial pressure of 14 in. of water, on to one surface of the specimen. The water emerges from a jet which allows the tap funnel to run dry in 22 secs. The jet is moved by hand over the surface of the specimen and about 1 in. from it. The movement of the point of impingement on the surface of the specimen is in a clockwise direction, and six complete circles are described during the douching.

Weighing.—The corrosion of the specimens is measured in terms of loss in weight per unit area after the removal of the corrosion products by means of Clarke's solution.*

Using the foregoing equipment and *modus operandi*, two sets of spray tests on the 14 materials were carried out, spraying with *N*/100 sulphuric acid. Notes on the appearance of the specimens during the two sets of tests are given in the appendix. The experimental details and results of the tests are recorded in Table II.

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[8] W. H. Hatfield and H. T. Shirley, T. Swinden and W. W. Stevenson, J. C. Hudson and T. A. Banfield: Fourth Report of the Corrosion Committee, p. 159, Iron and Steel Institute, 1936, *Special Report No.* 13.

[9] Fifth Report of the Corrosion Committee, p. 223, Iron and Steel Institute, 1938, *Special Report No.* 21.

*S. G. Clarke's de-rusting solution: Hydrochloric acid (100 parts) containing antimonious oxide (2 parts) and stannous chloride (5 parts).

TABLE II.
RESULTS OF FIRST SERIES OF SPRAY TESTS USING N/100 SULPHURIC ACID.
Spraying carried out for 20 days, 60 cycles per day.

Material.	Mean Loss of Weight per Standard Specimen.* G.		Loss in Weight Referred to Steel X2 as 100.		
	First Test.	Second Test.	First Test.	Second Test.	Mean.
Carbonyl iron	0·701	0·522	86	100	93
Swedish Lancashire iron	0·873	0·598	107	114	110·5
Staffordshire wrought iron	0·851	0·570	104	109	106·5
Aston-Byers iron	0·950	0·608	116	116	116
Ingot iron	0·838	0·559	102	107	104·5
Rail steel	0·886	0·519	108	99	103·5
XK (0·2% C, solid)	0·849	0·495	104	95	99·5
ZK (0·2% C, 0·5% Cu, solid)	0·818	0·491	100	94	97
K (1% Cr)	0·826	0·488	101	93	97
L (0·6% C, 0·5% Cu)	0·752	0·509	92	97	94·5
N (1% Cr, 0·5% Cu)	0·778	0·477	95	91	93
O (0·5% Cu, 1·5% Mn)	0·829	0·476	101	91	96
X2 (0·2% C, balanced)	0·817	0·523	100	100	100
Z (0·2% C, 0·5% Cu, balanced)	0·803	0·490	98	93	95.5

* Total area of standard specimen, 16 sq. in.

Progress of the Tests and Modifications in the Apparatus

During the tests on *N*/100 sulphuric-acid spray, difficulty was experienced in maintaining a constant spray volume of equal intensity on the two faces of the specimens. This was due to the level of liquid in the spray bottles falling at slightly different rates during a day's run. The apparatus was therefore modified as follows: Instead of using bottles of spray liquid and adjusting the spray pressure periodically, a large aspirator full of liquid is placed 10 ft. above the level of the spray apparatus. The spray liquid is passed from the aspirator through a device (shown in Fig. 3) which ensures a constant flow of liquid, independent of either the hydrostatic pressure or the back pressure of the air blast. After passing through this device, the stream of liquid is split into two equal streams, each passing through a length of fine capillary tubing, and thence to the spray nozzles. The spray liquid is converted into a fine nebula by the air blast, which is kept constant at a definite pressure.

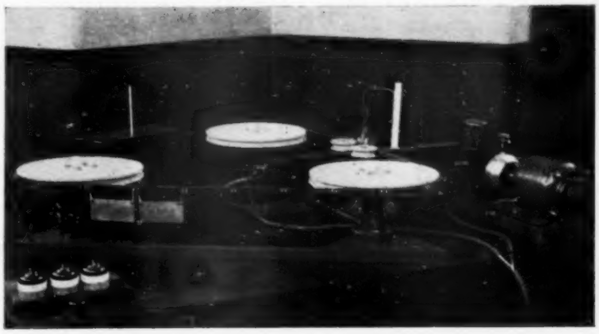

Fig. 2.—The new equipment for accelerated spray tests.

Two additional duplicate sets of tests on the 14 materials were carried out on the spray apparatus modified as above, using (*a*) *N*/20 sulphuric acid and (*b*) a mixed solution containing equal proportions of *N*/50 sulphuric acid and *N*/50 sodium chloride—i.e., centinormal in respect to each constituent. Observations on the progress of the spray tests are given in the appendix, and the results of both series of tests are given in Table III. The two sets of spray tests using the mixed solution were controlled at different spray intensities, and this is reflected in the loss-of-weight figures. It is seen that the volume of spray liquid falling on the surface of the specimens does not affect materially the order of merit obtained. It should be noted, however, that in all cases the volume of spray was so controlled that the droplets impinging on the specimens did not completely wet the surfaces. This is discussed later. Duplicate field tests were also carried out for one year in the semi-industrial atmosphere at Stocksbridge (seven of the materials had been the subject of previous one-year field tests at Stocksbridge[8]). Observations on the progress of the corrosion are given in the appendix, and the results are listed in Table IV.

As a result of the good agreement, discussed later, between the long-period field tests and the sulphuric-acid/sodium-chloride spray tests, it was decided to build an

TABLE III.
RESULTS OF THE SECOND SERIES OF SPRAY TESTS USING (*a*) N/20 SULPHURIC ACID, AND (*b*) A SOLUTION OF N/100 SULPHURIC ACID, N/100 SODIUM CHLORIDE.
Spraying carried out for 20 days, 60 cycles per day.

Material.	N/20 Sulphuric Acid.					Mixed Solution (N/100 Sulphuric Acid, N/100 Sodium Chloride).†				
	Mean Loss of Weight per Standard Specimen.* G.		Loss in Weight Referred to Steel X2 as 100.			Mean Loss of Weight per Standard Specimen.* G.		Loss in Weight Referred to Steel X2 as 100.		
	First Test.	Second Test.	First Test.	Second Test.	Mean.	First Test.	Second Test.	First Test.	Second Test.	Mean.
Carbonyl iron	0·628	0·860	100·5	102	101	0·752	1·784	158	133	145·5
Swedish Lancashire iron	0·679	0·937	109	111	110	0·771	2·106	162	156·5	159
Staffordshire wrought iron	0·598	0·832	95·5	99	97	0·476	1·216	100	91	95·5
Aston-Byers iron	0·693	0·947	111	112	111·5	0·662	1·711	138	127	132·5
Ingot iron	0·628	0·890	100·5	106	103	0·575	1·520	115	113	114
Rail steel	0·631	0·890	101	106	103·5	0·462	1·266	97	90	93·5
XK (0·2% C, solid)	0·628	0·826	100·5	98·5	99·5	0·460	1·323	97	99	98
ZK (0·2% C, 0·5% Cu, solid)	0·581	0·783	93	93	93	0·415	1·186	87	88	87·5
K (1% Cr)	0·603	0·767	96·5	91	93·5	0·420	1·293	88	96	92
L (0·6% Cr, 0·5% Cu)	0·584	0·747	93·5	89	91	0·413	1·121	87	83	85
N (1% Cr, 0·5% Cu)	0·551	0·724	88	86	87	0·387	1·116	81	82	81·5
O (0·5% Cu, 1·5% Mn)	0·581	0·749	93	89	91	0·437	1·138	92	85	88·5
X2 (0·2% C, balanced)	0·625	0·841	100	100	100	0·476	1·346	100	100	100
Z (0·2% C, 0·5% Cu, balanced	0·590	0·791	94·5	94	94	0·428	1·251	90	92	91

* Total area of standard specimen, 16 sq. in.

† Two sets of tests operated at different spray intensities.

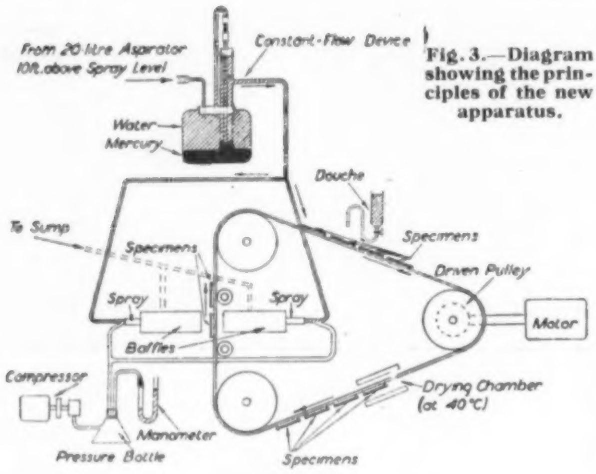

Fig. 3.—Diagram showing the principles of the new apparatus.

TABLE IV.

RESULTS OF FIELD TESTS CARRIED OUT AT STOCKSBRIDGE. 27/7/37 to 27/7/38.

Material.	Mean Loss of Weight per Standard Specimen.* G.			Loss in Weight Referred to Steel X2 as 100.
	A.	B.	Mean.	
Carbonyl iron	9·86	9·23	9·54	126
Swedish Lancashire iron	9·61	9·94	9·77	129
Staffordshire wrought iron	7·49	6·96	7·22	95·5
Aston-Byers iron	8·58	8·28	8·43	111
Ingot iron	8·14	8·25	8·19	108
Rail steel	6·89	6·89	6·89	91
XK (0·2% C, solid)	6·59	6·99	6·79	90
ZK (0·2% C, 0·5% Cu, solid)	5·85	5·70	5·77	76
K (1% Cr)	6·45	6·30	6·37	84
L (0·6% Cr, 0·5% Cu)	5·46	5·43	5·44	72
N (1% Cr, 0·5% Cu)	5·00	4·98	4·99	66
O (0·5% Cu, 1·5% Mn)	5·88	5·91	5·89	78
X2 (0·2% C, balanced)	7·64	7·50	7·57	100
Z (0·2% C, 0·5% Cu, balanced)	6·19	6·33	6·26	83

* Total area of standard specimen, 16 sq. in.

entirely new equipment. This is shown in Fig. 2, and incorporates additional improvements, in that a direct drive through the gearbox is used instead of a belt-drive, and the apparatus has greater stability, achieved by lowering the travelling belt and using metal and Sindanyo parts, instead of wood. Also, the carbon-filament heater lamps were replaced by a strip heater covered by a sheet of stainless steel. This was necessary to accommodate the drying section of the apparatus in the new layout and had the added advantage that the thermometer was not directly exposed to radiation from the carbon-filament lamps. Fig. 3 shows the entire equipment diagrammatically. The results obtained for duplicate tests on 13 materials, using the new equipment, are given in Table V. Observations of the progress of the corrosion were made, but have not been included, as they bore such great similarity to the observations recorded in the appendix in connection with the earlier spray tests using the mixed sulphuric-acid/sodium-chloride solution. For the tests reported in Table V the spray volume was controlled to give the maximum wetting of the specimens consistent with maintaining the individuality of the droplets on the surface of the specimens. For the purpose of judging droplet size, a stainless-steel contro' specimen was incorporated in each series of tests. Since this specimen does not corrode, it is possible to judge the spray volume with greater accuracy, as compared with the spraying of a surface coated with hydrated oxide.

The orders of merit for the 14 materials in the field tests and the three types of spray tests are given in Table VI, whilst Table VII shows the orders of merit for seven steels which have been the subject of two long-period field tests at Stocksbridge and three types of spray tests.

TABLE V.

RESULTS OF THE THIRD SERIES OF TESTS USING THE NEW SPRA EQUIPMENT AND SPRAYING WITH A SOLUTION OF N/100 SULPHURIC ACID, N/100 SODIUM CHLORIDE.

Spraying carried out for 20 days, 60 cycles per day.

Material.	Mean Loss of Weight per Standard Specimen.* G.		Loss in Weight Referred to Steel X2 as 100.		
	First Test.	Second Test.	First Test.	Second Test.	Mean.
Swedish Lancashire iron	2·40	2·51	170	141	155·5
Staffordshire wrought iron	1·53	1·82	109	102	105·5
Aston-Byers iron	1·92	2·42	136	136	136
Ingot iron	1·74	2·51	123	141	132
Rail steel	1·38	1·74	98	98	98
XK (0·2% C, solid)	1·43	1·84	101	103	102
ZK (0·2% C, 0·5% Cu, solid)	1·32	1·66	94	93	93·5
K (1% Cr)	1·35	1·67	96	94	95
L (0·6% Cr, 0·5% Cu)	1·20	1·53	85	86	95·5
N (1% Cr, 0·5% Cu)	1·18	1·42	84	80	82
O (0·5% Cu, 1·5% Mn)	1·29	1·74	91	98	94·5
X2 (0·2% C, balanced)	1·41	1·78	100	100	100
Z (0·2% C, 0·5% Cu, balanced)	1·25	1·61	89	90	89·5

* Total area of standard specimen, 16 sq. in.

In the first set of spray tests, using *N*/100 sulphuric acid, the orders of merit for certain materials were in reasonably good agreement with the field-test results but the "spread" of the results was of a very low order. In fact, of 28 tests carried out on 14 materials, the highest and lowest loss-of-weight results (referred to the standard steel *X*2 as 100) were 116 and 86, respectively, the 86 result being an isolated figure, the next lowest being 91. For the second series of spray tests, therefore, an attempt was made to increase the relative corrosion of the materials. Two methods were adopted,—*viz.*, (*a*) increasing the acidity, and (*b*) introducing a second acid radical in the form of a salt addition.

TABLE VI.

ORDERS OF MERIT FOR 14 STEELS AND STEELS AND IRONS IN FIELD TESTS AND THREE TYPES OF SPRAY TESTS AT STOCKSBRIDGE.

Material.	Field Tests. 27/7/37 to 27/7/38.	Spray Tests.			
		N/100 Sulphuric Acid, N/100 Sodium Chloride.		N/100 Sulphuric Acid.	N/20 Sulphuric Acid.
		Old Equipment.	New Equipment.		
Carbonyl iron	13	13	..*	1	10
Swedish Lancashire iron	14	14	13	13	13
Staffordshire wrought iron	9	8	10	12	7
Aston-Byers iron	12	12	12	14	14
Ingot iron	11	11	11	11	11
Rail steel	8	7	7	10	12
XK (0·2% C, solid)	7	9	9	8	8
ZK (0·2% C, 0·5% Cu, solid)	3	3	4	6	4
K (1% Cr)	6	6	6	6	5
L (0·6% Cr, 0·5% Cu)	2	2	2	3	2
N (1% Cr, 0·5% Cu)	1	1	1	1	1
O (0·5% Cu, 1·5% Mn)	4	4	5	5	2
X2 (0·2% C, balanced)	10	10	8	9	9
Z (0·2% C, 0·5% Cu, balanced)	5	5	3	4	6

* Carbonyl iron was not tested in this series.

The results in Table III show that method (*a*) had no appreciable effect on the "spread" of the results; the increased acidity of the solution caused acid attack, with sulphate formation and deposition on the specimens, and, apart from the relatively poor order of merit revealed, could not be regarded as an improvement on the *N*/100 sulphuric acid solution used for the first series of tests. On the other hand, the mixed sulphuric-acid/sodium-chloride solution increased the "spread" of the results materially—the maximum and minimum of the first set being 162 and 81, respectively—at the same time giving orders of merit very close to those of the one-year field tests. The actual loss-of-weight figures for the first set however, were considered to be on the low side, with the result that a definite increase was made in the volume of spray used, and a decrease in droplet size, for the duplicate tests with the mixed liquid. The corrosion rate was thus increased by two to three times that of the first set, and a fairly wide "spread" was also obtained—maximum 156·5, minimum 82. The agreement of the second set with one-year field tests, with respect to orders of merit, was quite good, as in the first set. It should be noted in the tables that the mean of the loss-of-weight figures (referred to steel X2 as 100) has been taken to obtain the reported orders of merit for all the tests.

TABLE VII.

ORDERS OF MERIT FOR SEVEN STEELS IN TWO SERIES OF FIELD TESTS AND THREE TYPES OF SPRAY TESTS AT STOCKSBRIDGE.

Material	Field Tests.		Spray Tests.			
	A. 12/6/35 to 11/6/36.	B. 27/7/37 to 27/7/38.	N/100 Sulphuric Acid, N/100 Sodium Chloride.		N/100 Sulphuric Acid.	N/20 Sulphuric Acid.
			Old Equipment.	New Equipment.		
XK (0·2% C, solid)..	6	6	6	7	6	6
ZK (0·2% C, 0·5% Cu, solid)........	3	3	3	3	4	4
K (1% Cr)	5	5	5	5	4	5
L (0·6% Cr, 0·5% Cu)	2	2	2	2	2	2
N (1% Cr, 0·5% Cu)..	1	1	1	1	1	1
O (0·5% Cu, 1·5% Mn)	3	4	4	4	3	2
X2 (0·2% C, balanced)	7	7	7	6	7	7

The tests carried out on the new equipment were virtually made under the same experimental conditions as those used for the second set of sulphuric-acid/sodium-chloride spray tests. The results of the new equipment tests are given in Table V, and similar observations may be made in regard to them. The actual loss of weight is reasonably high—from 1·18 to 2·51 g. on 125-g. specimens—the "spread" of the results is quite good, and the orders of merit for 13 materials are reasonably close to those obtained in one year's atmospheric exposure.

Conclusion

In the view of the authors, the accelerated spray test described is of sufficient promise to be regarded as the basis of a laboratory method for the determination of the relative corrodibility of irons and constructional steels. In order to obtain reliable results by this method, certain experimental conditions should be adhered to, as postulated below:

1. Visible acid attack should not occur. Acid attack was obtained with *N*/20 sulphuric acid, but not with *N*/100 acid under the conditions prevailing in the authors' experiments. Hence, the maximum permissible acid concentration is at some stage between these two limits.
2. The spray should consist of very fine droplets, each droplet being surrounded by air.
3. The stainless-steel control specimen should not be *completely* wetted. This is determined experimentally by the size and intensity of the sprays, and the time taken in passing the sprays. This affords a ready means of avoiding excess spray liquid on the specimens, which would reduce the rate of oxygen supply to them.

The results have been placed on record for the main purpose of encouraging other workers in this field, who may consider it worth while to pursue the method with other spray solutions, or may introduce other modifications for the additional improvement of the method. It is well known that the relative corrodibility of ferrous materials differs in different types of atmosphere, and it is thereby feasible that a spray solution which gives the Stocksbridge or Sheffield order of merit may not be suitable for reproducing the order of merit obtained in urban or marine atmospheres. Further research in this direction is necessary.

Acknowledgements

The authors express their thanks to the members of the Laboratory Corrosion Sub-Committee, particularly Dr. U. R. Evans, Dr. G. D. Bengough, F.R.S., and Dr. J. C. Hudson, for helpful encouragement during the progress of the work; to Mr. H. Padget for carrying out the experimental work; and finally to the Directors of the United Steel Companies Limited, for the necessary permission for publication.

Appendix—Summary of Observations on the Progress of the Tests

First Series of Spray Tests Sprayed with N/100 Sulphuric Acid.—All specimens except carbonyl iron completely rusted to lighter brown in one day. Carbonyl iron completely rusted in four days. During the course of the test the rust on all specimens became progressively darker and thicker. Steel O had the darkest-coloured rust, and the irons were somewhat lighter and more red than the steel specimens, which were generally dark brown in colour.

Second Series of Spray Tests Sprayed with N/20 Sulphuric Acid.—All specimens completely rusted to dark purplish brown in one day. During the course of the test the rust on all specimens became progressively darker and thicker, finishing much darker in colour than that produced by atmospheric corrosion at Stocksbridge. There was definite evidence of sulphate on the surfaces of all the specimens from an early stage in the tests.

Second Series of Spray Tests Sprayed with N/100 Sulphuric Acid, N/100 Sodium Chloride.—All specimens except carbonyl iron completely rusted to light brown after two days; carbonyl iron rusted completely in three days. During the course of the test all materials progressively darkened and finished dark brown in colour. The second set of specimens had much coarser rust than the first set owing to the increased spray volume.

Atmospheric Exposure for One Year Facing North and South.—All specimens rusted to red-rust colour in one day, owing to the action of dew. During dry periods the rust became lighter in colour, and there was a tendency for the south face to be slghtly lighter than the north During the course of the test the rust became gradually darker in colour, and from time to time patches of thick rust were shed. At the end of the test all the specimens were dark brown in colour, the irons being slightly lighter and steels K, L and N being slightly darker than the remainder.

E. G. ACHESON, LTD., manufacturers of "Dag" colloidal products have moved from Thames House, Millbank, London, S.W. 1, to temporary premises at 9, Gayfere Street, Westminster, London, S.W. 1. Telephone numbers Abbey 3366/7/8.

WILD-BARFIELD ELECTRIC FURNACES LTD, Elecfurse Works, Watford By-Pass, Watford, have been appointed distributors, in the United Kingdom, of the Spekker Steeloscope, manufactured by Messrs. Adam Hilger Ltd., of London. Many readers will be familiar with this small, useful instrument which brings spectroscopic analysis within the reach of most engineering firms. In its simplest form this instrument can be used as an immediate check and means for sorting steels delivered from suppliers. With the Insta eyepiece, at slightly extra cost, it is a valuable addition to any metallurgical laboratory for accurate visual quantitative analysis.

Wild-Barfield Electric Furnaces Ltd have installed a complete equipment in their new research department, and advise us that they will be happy to give practical demonstrations to any interested readers.

The Manufacture of Steel by the Perrin Process

By B. Yaneske

(Chemical, Metallurgical and Research Department, The Tata Iron and Steel Co., Ltd., Jamshedpur, India).

A new steelmaking process is described in which molten pig iron containing about 0·3% of phosphorus is blown in an acid-lined Bessemer converter, and the resultant blown metal is rapidly dephosphorised by pouring it from a sufficient height into a basic oxidising slag contained in the casting ladle. Alloys are then added in a red-hot condition to the dephosphorised blown metal and the finished steel is cast into ingots. Low-carbon steel ingots can be manufactured by this method direct from the acid Bessemer converter when using a pig iron that is too high in phosphorus for the normal acid Bessemerprocess. This paper, prepared for presentation at the Autumn General Meeting of the Iron and Steel Institute, contains the results of many experiments; it is substantially abridged in this article.

The Perrin process of steelmaking, invented by Mr. R. M. V. Perrin, Director of the Société d'Electro Chimie, d'Electro Métallurgie et des Aciéries Electriques d'Ugine, France, consists of the treatment of molten steel by pouring it from a considerable height, say, about 20 ft., into a previously prepared synthetic slag contained in the casting ladle, or by other means churning the steel and slag together before casting the steel into ingots. Mr. Perrin claimed that his process could be used either for deoxidising or dephosphorising molten steel, by varying the composition of the synthetic slag.

For *deoxidising* purposes, the slag had to be highly silicious, the silica content being not less than 55%, and the iron oxide ($FeO + Fe_2O_3$) content essentially as low as possible, preferably not above 1%. During the churning operation it is claimed that oxygen in the form of ferrous oxide is absorbed by the slag from the steel—i.e., the steel is deoxidised not in the usual way, by the addition of deoxidisers, which gave rise to solid inclusions, but by the actual removal of the ferrous oxide in accordance with the following equation :—

$$2FeO + SiO_2 = Fe_2SiO_4.$$

At the same time, silicon also entered the steel by reduction of silica from the slag. Therefore a deoxidised steel free from non-metallic inclusions is the result, since no inclusions can be formed in the process, this assertion is stated to have been supported by practical results. About 3% of synthetic slag is considered sufficient to obtain a satisfactory degree of deoxidation.

For *dephosphorising* purposes, a highly basic oxidising slag is necessary, the lime content being preferred above 55%, and the iron oxide ($FeO + Fe_2O_3$) content not less than 25%. It is claimed that when molten steel is churned with this molten synthetic slag, the phosphorus in the steel is oxidised to phosphoric acid, which combined with the lime in the slag to form calcium phosphate according to the following equation :—

$$3CaO + P_2O_5 = Ca_3(PO_4)_2,$$

the calcium phosphate being retained in the slag. A considerable increase in the P_2O_5 content of the slag indicates the possibility of utilising the finished slag as an artificial fertiliser, if the percentage of phosphorus to be removed from the steel were sufficient. It was stated that after the churning operation there was a remarkable decrease in the total iron oxide content of the slag, which was sometimes diminished from 35% to as low as 6 or 7%, iron thus being reduced from the slag to the steel and so increasing the yield. Mr. Perrin also claimed that he had found the dephosphorisation to be very intensive, even when starting from a low initial phosphorus content, and that the exothermic dephosphorising reaction which occurred in the ladle was completed in less than 1 min. for 15 tons of steel.

As Mr. J. J. Ghandy (General Manager of the Tata Iron and Steel Co., Ltd., Jamshedpur, India) and the author had in view the economic application of Mr. Perrin's process for the manufacture of low-carbon steels direct from Tata blast-furnace iron containing 0·28–0·4% of phosphorus, after blowing it in an acid Bessemer converter, thus eliminating the basic open-hearth furnace for finishing the blown metal, they were more interested in the *dephosphorising* process. It was therefore arranged with Mr. Perrin that two experiments in dephosphorisation would be carried out at the Ugine steelworks, and Mr. Ghandy and Mr. Yaneske visited the steelworks at Ugine for that purpose.

Preliminary Experiments at the Ugine Steelworks

(A) *Dephosphorising Experiment with very low Manganese.*

The object of this experiment was to dephosphorise in the ladle to below 0·05% of phosphorus, steel which was low in carbon, manganese and silicon, but contained about 0·3% of phosphorus. This composition would therefore be similar to that of the Bessemer soft blows at the duplex plant of the Tata Iron and Steel Works at Jamshedpur, India, where the duplex process is operated by blowing iron in a 25-ton acid Bessemer converter and then transferring the blown metal to a 250-ton basic open-hearth tilting furnace to dephosphorise and finish the steel to the required chemical specification.[1] The experiment would therefore demonstrate the possibility of dephosphorising Tata Bessemer blown metal by the Perrin process.

Mr. Perrin stated that in order to remove about 0·275% of phosphorus from the steel, he considered about 10–12% of synthetic slag would be necessary in the experiment, but this amount could be reduced to about 7% by well shaking the steel and slag together, or by pouring the steel into the slag from a height of not less than 20 ft. Mr. Perrin was of the opinion that by using only 7% of slag it would be possible to obtain about 10% of P_2O_5 in the slag after the mixing operation.

Preparation of the Dephosphorising Slag.—A synthetic basic slag was prepared in a 5-ton Girod-Héroult basic-lined electric-arc furnace. The slag consisted of a mixture of lime, iron ore and a little fluorspar. In order to start making the slag, 2,500 kg. (2½ tons) of Armco iron were charged in the empty furnace in order to produce the necessary electric circuit. On the top of this iron, the following ingredients for making the slag were charged :—

	Kilogs.	Cwts.
Lime (CaO 85%)	1,400	(28)
Iron ore (FeO 65%)	800	(16)
Fluorspar (CaF_2 85%)	175	(3½)

Mr. Perrin was aiming at the following composition of the slag, with which he previously had obtained very good results :—

CaO. %.	$FeO + Fe_2O_3$. %.	SiO_2, Al_2O_3, MgO, &c. %.
60	30	10

---

[1] The duplex process as operated in India at the works of The Tata Iron and Steel Company has been described by the author in a paper published in the *Journal of the Iron and Steel Institute*, 1927, No. I., pp. 181-209.

Preparation of the Steel for Dephosphorising.—In an adjacent 15-ton Girod-Héroult basic-lined electric-arc furnace, a charge consisting of 12,000 kg. (12 tons) of plain carbon-steel bloom butts and broken rails was melted with 1,000 kg. (1 ton) of calcined lime. After the bath was clear melted, the slag was poured off. The following is a record of the heat from this stage :—

HEAT NO. 92,440. OCTOBER 8, 1935.

	P.M.
First slag poured off	3·25—3·28
Lime added to clean bath (200 kg. (4 cwt.))	3·30
All slag raked off	3·40—3·48
Ferro-phosphorus added, P 24%, Si 5% (150 kg. (3 cwt.))	3·50
Sample of steel	3·53
Furnace tapped (steel poured into slag)	3·54
Slag Furnace.	
Sample of Slag	3·43
Slag tapped into casting ladle (2,000 kg. (2 tons))	3·51

The pouring height from the furnace launder to the bottom of the casting ladle was approximately 14½ ft., and there was no visible reaction in the ladle when the steel was poured into the slag. The fire-brick lining of the ladle and the stopper were coated with magnesia cement.

The treated steel was cast through a 40 mm. (1 9/16 in.) diameter nozzle into open wide-end-up moulds, eight ingots of 1,600 kg. (32 cwt.) each being cast. After teeming, there was a skull weighing about 500 kg. (½ ton) left in the ladle bottom.

A sample of steel was taken for analysis after casting the fourth ingot, and a sample of slag immediately after all the steel was cast.

The quantity of aluminium added in the moulds was 2 kg. (4·4 lb.) to the first two ingots, which rose in the moulds, and 2½ kg. (5·5 lb.) to the other six ingots, which had flat tops.

The following are the analyses of the steel and slag samples :—

ANALYSIS OF STEEL.

	Before Mixing.	After Mixing.
C. %	0·04	0·05
Mn. %	0·04	0·03
S. %	0·013	0·013
P. %	0·252	0·066
Si. %	0·005	0·002

ANALYSIS OF SLAG.

	Before Mixing.	After Mixing.
SiO_2. %	4·75	5·36
Al_2O_3. %	1·36	1·28
FeO. %	25·80	29·96
Fe_2O_3. %	16·02	8·54
MnO. %	1·74	1·79
CaO. %	46·98	46·95
MgO. %	2·48	3·60
P_2O_5. %	0·19	2·03
TiO_2. %	Traces	Traces
S. %	0·045	0·053

Notes on the Experiment

(1) The phosphorus content of the steel before dephosphorising was found on analysis to be only 0·252% and not 0·3% as desired for the experiment.

(2) The phosphorus in the treated steel was 0·066% and therefore was not reduced below 0·05% as desired.

(3) The weight of the synthetic slag used was 15% of that of the steel plus the ladle skull, and was therefore much in excess of the amount regarded as necessary to effect the desired dephosphorisation.

(4) Although phosphorus had been removed to the extent of 0·186% (from 0·252 to 0·066%), the P_2O_5 content of the slag after mixing was only 2·03%, mainly due to the large percentage of dephosphorising slag used.

(5) The weight of ingots made was 12,800 kg. (12 tons 16 cwt.), whereas the total metallic charge was 12,150 kg. (12 tons 3 cwt.). Therefore, there was a gain of 650 kg. (13 cwt.), which can only be accounted for by some of the melted Armco iron from the slag furnace having been poured into the casting ladle with the synthetic slag.

(6) The CaO in the synthetic dephosphorising slag was only about 47% instead of 60% as desired. It was evident that the low lime content and high iron oxide content of the slag were brought about by dilution with some oxidised Armco iron charged in the slag furnace.

(7) There was very little decrease in the total iron oxide content of the slag after mixing, which was contrary to expectation.

(8) The treated steel was highly oxidised, as was evident from the fact that as much as 3·44 lb. per ton of aluminium was required to kill the steel in the moulds.

(B) *Dephosphorising Experiment with* 0·4% *of Manganese in the Steel.*

An experiment in the presence of so much manganese had never been attempted before by Mr. Perrin. As there was every possibility of the manganese being oxidised along with the phosphorus during the mixing of the steel and slag, if a slag of composition similar to that in the previous experiment were used, it was agreed that an addition of about 10% of MnO should be made to the slag for the present experiment, with the object of minimising the oxidation of manganese from the steel. As in the previous experiment, ferro-phosphorus would be added to yield about 0·3% of phosphorus in the steel, but in addition ferro-manganese would be added to yield about 0·4% of manganese.

The object of this experiment was to ascertain whether it would be possible to make low-carbon steels direct from the acid Bessemer converter, by blowing the carbon out of Tata blast-furnace iron until only about 0·1% remained, adding the required amount of ferro-manganese in the converter, and then removing the phosphorus by pouring the blown metal containing manganese into a previously prepared synthetic slag.

Preparation of the Dephosphorising Slag.—As in the former dephosphorising experiment, a synthetic slag was prepared in the 5-ton basic electric furnace.

On the bottom of the furnace 2,500 kg. (2½ tons) of Armco iron, and 1,000 kg. (1 ton) of 12% manganese steel scrap were charged. The latter was added with the object of producing MnO in the slag, so as to minimise the oxidation of manganese from the steel during the mixing with the synthetic slag in the casting ladle.

The mixture of Armco iron and manganese steel scrap was allowed to melt, after which the following slag ingredients were charged in the furnace :—

	Kg.	(Cwt.)
Lime (CaO 85%)	1,400	(28)
Manganese ore (MnO 65%)	400	(8)
Iron ore (FeO 65%)	400	(8)
Fluorspar (CaF_2 85%)	175	(3½)

Preparation of the Steel for Dephosphorising.—In the adjacent 15-ton basic electric furnace a charge consisting of 12,000 kg. (12 tons) of plain carbon-steel bloom butts and turnings was melted with 500 kg. (½ ton) of calcined lime. After the bath was clear melted, the slag was poured off. The following is a record of the heat from this stage :—

HEAT NO. 92,467. OCTOBER 10, 1935.

	P.M.
First slag poured off	4·36—4·40
Lime added to clean bath (200 kg. (4 cwt.))	4·43
All slag raked off	4·53—5·00
Ferro-manganese added, C 6%, Mn 80% (58 kg. (1/16 cwt.))	5·01
Ferro-phosphorus added, P 24%, Si 5% (150 kg. (3 cwt.))	5·02
Sample of steel	5·05
Furnace tapped (steel poured into slag)	5·06
Slag Furnace.	
Sample of slag	4·59
Slag tapped into casting ladle (2,000 kg. (2 tons))	5·04

The pouring height from the furnace launder to the bottom of the casting ladle was about 14½ ft., and there was only a mild reaction discernible in the ladle when the steel was poured into the slag. The firebrick lining of the ladle and the stopper were coated with magnesia cement.

The treated steel was cast through a 40 mm. (1 9/16 in.) diameter nozzle into wide-end-up moulds. Nine ingots of 1,600 kg. (32 cwt.) each without hot tops, and two ingots of 500 kg. (10 cwt.) each with hot tops were made. The two small ingots were cast into moulds with hot tops because there was much more steel than expected and no other moulds were available without hot tops. After teeming, there was a skull weighing about 200 kg. (4 cwt.) left in the ladle bottom.

A sample of steel was taken for analysis after casting the fourth ingot, and a sample of slag immediately after all the steel was cast.

In the moulds an addition of 2 kg. (4·4 lb.) of aluminium plus 2½ kg. (5·5 lb.) of silicon-aluminium alloy (Si 35%, Al 45%) was made to each ingot weighing 1,600 kg. (32 cwt.), and 1¼ kg. (2·75 lb.) of aluminium to each ingot weighing 500 kg. (½ ton). The larger ingots had flat tops, while the smaller ingots cast with hot tops had sunken heads.

The following are the analyses of the steel and slag samples :—

ANALYSIS OF STEEL.

	Before Mixing.	After Mixing.
C. %	0·08	0·07
Mn. %	0·42	0·26
S. %	0·029	0·016
P. %	0·253	0·076
Si. %	Nil	0·003

ANALYSIS OF SLAG.

	Before Mixing.	After Mixing.
SiO_2. %	6·86	8·98
Al_2O_3. %	1·24	1·94
FeO. %	12·87	18·70
Fe_2O_3. %	14·54	5·98
MnO. %	10·42	11·08
CaO. %	51·65	47·55
MgO. %	1·56	2·58
P_2O_5. %	0·22	2·38
TiO^2. %	Traces	Traces
S. %	0·048	0·081

Notes on the Experiment

(1) As in the previous experiment, the phosphorus content of the steel was found on analysis to be low, being 0·253%, against 0·3% desired.

(2) The phosphorus in the treated metal was 0·076%, and therefore was not reduced below 0·05% as desired.

(3) The weight of synthetic slag used was nearly 13% of the weight of steel plus the ladle skull.

(4) Although phosphorus had been removed to the extent of 0·177% (from 0·252 to 0·066%), the P_2O_5 content of the slag after mixing was only 2·38%, mainly owing to the large percentage of dephosphorising slag used.

(5) The presence of more than 10% of MnO in the slag did not prevent the oxidation of some of the manganese which was reduced from 0·42% to 0·26% during the dephosphorising reaction.

(6) The weight of ingots made was 15,400 kg. (15 tons 8 cwt.), whereas the total metallic weight charged was 12,208 kg. (12 tons 4 cwt.). Therefore, there was a gain of about 3,200 kg. (3 tons 4 cwt.), so that it is certain that the whole of the Armco iron and manganese steel scrap was melted and tapped into the casting ladle along with the dephosphorising slag.

(7) The CaO in the synthetic slag was 51·65%, which was more than in the previous experiment, but still lower than desired. This was evidently due to dilution with some oxidised Armco iron and manganese-steel scrap charged in the slag furnace.

(8) As in the former experiment, there was very little reduction in the total iron content of the slag after mixing.

(9) The treated steel was highly oxidised, as indicated by the large additions of aluminium (2·75 lb. per ton) plus silicon-aluminium alloy (3·44 lb. per ton) which were required to kill the steel in the moulds.

Although the two foregoing experiments in dephosphorisation carried out at the Ugine steelworks were only partly successful and left much to be desired, they were considered by Mr. Ghandy and the author to be sufficiently encouraging to justify the conducting of further experiments at the Tata works in India.

The result was that upon the author's return to India, an exhaustive series of experiments was carried out under his supervision at the Tata duplex plant, as circumstances permitted. In all, one hundred experiments were conducted, of which particulars of a selection are contained in the paper. Altogether, in these experimental heats made over a period of two years, more than 3,000 tons of ingots were produced by the slag-dephosphorising direct process, with an average yield of 90·35% of ingots from blast-furnace iron plus alloy additions ; and as the ingots were rolled into various products mostly with satisfactory mill yields, it was considered that the experimental stage had been passed and sufficient information obtained to ensure that the Perrin process could be operated successfully on a commercial scale in a new plant specially designed for the process. It should also be mentioned that several ingots were sliced horizontally and longitudinally for a thorough metallurgical examination and for comparison with similar types of ingots made by the basic open-hearth and duplex processes, and it was found that the ingots made by the slag dephosphorisation process were in no way inferior to ingots made by the other processes. In fact, the results of the experiments were considered to be so satisfactory that the Tata Iron and Steel Co. purchased the patent rights for the Perrin process for India and Burma, and are erecting a new plant to operate the process on a site adjacent to the existing duplex plant at Jamshedpur.

As only soft steels up to about 0·15% of carbon can be made direct from the Bessemer converted by the Perrin process, it will be necessary when producing higher-carbon and alloy steels to charge the dephosphorised blown metal into a melting furnace (either acid or basic lined) for the addition of the necessary carbon and alloys.[2]

Perrin Process Plant : Method of Operation

Blast-furnace iron of suitable composition (1·1–1·3% of silicon and 0·3–0·6% of manganese) will be delivered in 60-ton ladles to the Perrin process plant and poured into the hot metal mixer by means of a 100-ton ladle crane. Twenty-four tons of mixer iron will be poured from the hot metal mixer into a 30-ton ladle supported on an electrically driven ladle car by which it will be conveyed to one of the 25-ton Bessemer converters. The iron will then be poured into the converter by means of an electrically operated tilting device.

For the production of low-carbon steel ingots direct from the converter, the iron will be blown until the carbon is about 0·1%. The required weight of dephosphorising slag will be poured from the slag mixer into a casting ladle of 50 tons capacity, supported on a truck, just prior to the converter being turned down. An electric lorry will then place the ladle under the converter, and the blown metal will be poured slowly into the dephosphorising slag from a height of more than 20 ft. Immediately the dephosphorising reaction has subsided, the ladle of slag and metal will be transferred under the chute of one of the ferro-manganese roasting furnaces, and the red-hot lump alloy will be ejected therefrom and will fall down the chute into the casting ladle. The latter will then be conveyed to a position from where it can be hoisted by one of the 100-ton ladle cranes and carried to the casting platform. Five minutes after the addition of the ferro-manganese the steel will be cast into ingots. Four moulds on stools will be set on one ingot bogie, and, taking the yield at 90%, four ingots each weighing 108 cwt. will be cast.

For the production of higher-carbon and alloy steels, the Bessemer blow will be stopped at a higher carbon content than that required by the chemical specification of the steel The dephosphorised blown metal containing carbon will be hoisted by one of the 100-ton ladle cranes and poured down a chute into one of the finishing furnaces. Four

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[2] For the production of higher-carbon and certain alloy steels, Mr. Perrin has conceived the idea of pouring the dephosphoriced blown metal back into the same or into another hot acid converter, the basic slag being thus separated from the treated metal. Silicon and/or manganese are next added to the dephosphorised metal, which is then blown for a few seconds to oxidise the elements added, and so to increase the heat of the metal to ensure a sufficiently high casting temperature. After turning down the converter, the required final alloy and carbon additions are made either in the converter or in the casting ladle, according to the chemical specification of the steel required.

[*Continued on page* 164

Refractories for High-Frequency Induction Furnaces

By L. F. Keeley

Steel-melting conditions are exceptionally severe on refractories, particularly when high-frequency induction furnaces are used, and the demands of users are increasingly difficult to meet. Few severer tests of a refractory can be encountered than a furnace lining, and the author describes the lining of a furnace, and discusses the types of refractories used for this purpose. Particular attention is given to lining life and patching.

IT is now 12 or 13 years since high-frequency furnaces were established in this country for the melting of steel (prior to this they were used only for experimental melts and for precious metals in small units, usually employing magnesia crucibles) and the refractory lining problem has passed from the trial state to something approaching standardised practice. In spite of this, both users and consumers are continually striving to produce something better, and few severer tests of a refractory can be met with than as a furnace lining, often with only a thickness of under two inches to accommodate a temperature gradient of 1,600° C. down to 20° C. Add to this the difficulty of patching a smooth vertical wall, and also the mechanical and thermal shocks suffered, and it will be realised how ably the refractory producers have responded to the demand.

The large graphite pots used in the early days did not attain universal success, and although they possess good strength and elasticity, they cannot compare with acid or basic rammed linings for length of life. They possess some advantages in being easily changed, and, on account of their conductivity, quickly heated up, but the geatest and insuperable drawback is the carbon pick-up. This makes them useless for stainless steels with their high percentage of chromium, as the latter element has such a marked affinity for carbon.

Pre-fired monolithic linings and linings built up of pre-fired rings and segments were tried, but were doomed to failure on account of their lack of elasticity and inability to withstand thermal shock. Segments used in the green state do not suffer this disability, and will be mentioned later. They were superseded by the "Rohn" process of ramming *in situ* a lining of crushed refractory, which method is almost universal to-day, and a brief description of the *modus operandi* may not be out of place here.

Ramming a Lining

First, the furnace coil is seen to be perfectly rigid in the furnace frame and firmly seated on a level base of firebricks or insulating bricks. The bottom is then made by tamping 3 in. or more of lining material on to the brick base inside the coil. The inside of the coil should previously have been plastered smooth with some heat-resisting fire-clay cement, and dried out. A mild-steel templet or "former" usually $\frac{3}{16}$ in. steel sheet, whose external shape is that of the inside of the furnace lining desired is then centred inside the coil.

An annular space between the coil and the former, 2 in. wide in the case of a 5-cwt. furnace, should be left—e.g., a 13-in. diameter former would be used for a 17-in. diameter coil. Slightly thicker linings would be made for larger furnaces—e.g., $2\frac{1}{2}$ in. for a 12-cwt. furnace. The former should then be filled with iron or scrap to weight it down, and if desired wooden distance pieces 2 in. square can be put at four points between the coil and the former to keep the latter centred. These, of course, are removed as ramming proceeds, and are not necessary if the ramming is done uniformly.

Great care must be exercised in tamping-in the lining material, and only small amounts should be added at a time, as with ramming other types of furnace hearths. The grading, about which more later, must not be disturbed, and the material should be added with a circular motion, and not tangentially from a broad shovel, as it can be demonstrated by using two concentric glass cylinders of different diameters that this causes the large particles to bounce off the outer wall and segregate on the inner face.

After each addition is tamped down, the surface should be roughened with a sharply-pointed rod to key the next layer, and prevent lamination. Power ramming is not suitable, as this would distort the coil. Great cleanliness is necessary, even a small piece of fibre from a containing sack might give rise to a runner. After ramming the sides, the top can be finished off with compo, and the lining is ready to be fritted in.

The coil, which may consist of 20 or more turns of flat copper tubing, carries the cooling water as well as the current. The voltage across the ends of the coil will be about 1,200 volt, and when the power is switched on, the former and metallic charge form the secondary circuit and, by virtue of eddy currents induced, the charge heats up and finally melts. At first, for perhaps two hours the power input is kept low, just sufficient to bring the former to a red heat but not to melt it, until the lining is thoroughly dried out. The power is then brought up until the weld on the former gives way, and melting proceeds. After pouring this first melt, a nicely-glazed pot should be left that will last for 50 to 100 further heats. These subsequent heats may take only an hour each, more or less according to the power input.

The depth of the fritted portion of the lining which starts at the inner face in contact with the molten metal, is important, and is governed by the nature of the refractory and the amount of bond present. If the material is so pure that it will not fritt, some bond, such as iron oxide, must be added, but not so much as to cause the lining to fritt right through and become like stone for then it would crack like the pre-fired material. What is desired is a backing of powdery unfritted material to accommodate the expansions and contractions, and to give some measure of heat insulation.

In place of a steel former, a plug made from a carbon electrode may be used, and withdrawn after fritting. A very high temperature such as would spoil a heat of steel can be obtained by this method, which is useful for highly-refractory material. Another method of dispensing with a former is to use unfired bricks. These have the advantage of being formed under much greater pressure than is possible in hand ramming, and the grading can be closely controlled. Correctly assembled, they give excellent results, but they are fragile from a transport viewpoint, and the joints may constitute a source of weakness. Also ordinary lining material is still required for the bottom and as a backing.

A five-hundredweight furnace lining is built up of three rings, each ring consisting of four or more curved, tongued-and-grooved bricks. The first course must be set off perfectly level, usually with the tongues downwards in the bottom which consists of about 3 in. of lining material. Jointing material, finely ground and made into a paste must be used.

Grading

It is necessary to have material composed of particles of different sizes which, when intermixed will produce a "grist" that will pack correctly and remain tight of texture with as few voids as possible. This is obtained by using material of three different grades. Firstly, a grade of coarse material is chosen which is acutely angular and which packed alone gives a reasonably-tight texture held together by its own peculiar particle shape. This packing leaves voids which require filling with a second-grade of smaller material, and this, in turn, leaves smaller voids which are filled with a grading of "flour." This gives a maximum density to withstand the attack of metal and slag.

Examples of gradings of commercial linings are given below:

I.M.M. Sieves.	Acid.	Basic.
On 20.	35%	45%
Through 20 on 60.	16%	10%
Through 60.	49%	45%

Types of Refractory Linings

Acid linings are made from ganister rock containing not less than 97% SiO_2 with 1·5 to 2·0% oxide of iron. The ganister is first calcined at 1,200° C. and subsequently crushed and graded. These linings are quite foolproof, and show no signs of cracking after repeated heatings and coolings, and are safe for the largest furnaces. This is partly because they rapidly acquire a deep fritt. Their density and resistance to slag penetration is less than that of basic linings, and they cut badly at the slag line when thin high-manganese slags are encountered. With the more usual thick glassy slag, however, they tend to build up on the slag line.

Basic linings are founded on some type of magnesite, with or without additions of other refractories. The magnesite rock must be fully calcined at 1,650° C. to be suitable for use as high-frequency furnace lining. Often the lining is a blend of Austrian and Grecian magnesite, typical analyses of which are given below.

	Austrian.	Grecian.
MgO	85·4%	93·0%
SiO_2	2·0%	2·6%
Fe_2O_3	8·0%	2·75%
CaO	2·5%	2·5%
Al_2O_3	0·8%	0·2%
TiO_2	0·1%	—

The colour of the dead-burned magnesia depends on the kind of magnesite rock from which it is produced, and the proportion of impurities. A magnesite with 5% of iron oxide is a dark brown chocolate colour, although imperfectly burned material may show a lighter colour and thus be deemed purer, it will shrink in use considerably. The Grecian magnesite has a higher MgO content and a very low content of flux, Fe_2O_3, and can be distinguished as white grains in the coarse part of the lining. As it is desirable to burn in a strong pot as soon as possible the major portion of the mix is Austraian.

Even when all precautions are taken, straight magnesia pots are liable to develop cracks on cooling. These are seldom of any moment on account of the depth of unfritted backing material and the cranks seal themselves on heating up.

Some brands of lining incorporate up to one-third of alumina to promote the formation of a spinel—a silicate of aluminium, as this does not expand and contract much. This adds considerably to the cost, but may be justified by the absence of cracks. A much later development is "synthetic" magnesia obtained from dolomite, which is of great importance to those countries lacking domestic supplies of magnesite. One method is the treatment of calcined dolomite with solutions of magnesium salts, whereby a molecular exchange reaction the calcium content of dolomite is replaced by the magnesium content of the added salt.*

Lining Life and Patching

Unless special precautions are taken, the top of the furnace lining can be very troublesome. That part, which is above, and not in contact with the molten metal, does not get fritted, and must be strengthened by other means. One method is to brick the top, and another is to put a steel ring inside the top—except just in front of the pouring spout. A simple and effective way of making the top portion set hard is to moisten the lining material above the slag line with a solution of sodium silicate (waterglass or magnesium chloride).

As the pot wears away and thus increases in diameter, a given weight of metal charged will be lower down in relation to the coil. This can be raised by tamping an in or so of lining on to the bottom, and covering with a piece of asbestos board, or disc from a saw-plate. After melting, this will give a new bottom perfectly fritted-in.

Patching the sides is not quite so easy, and is best done when the furnace is cold with one of the specially-made cements such as Thermo-patch. This is slapped on moist after seeing that the place to be patched is free from adhering slag. After the lining has been in use some time, it will be found that on removing the top ring quite a considerable amount of new lining material can be poked down the back of the lining next to the coil. By these various means the useful life of a lining can be prolonged, but when there exists any doubt, it is best to knock out the lining, and reline. Repairs to the coil and the delay that ensues are much more expensive than the cost of a few hundredweights of lining and a former. Apart from special devices and visual evidence, an experienced melter can tell when a lining is wearing thin by the voltmeters and ammeters on the control panel, which are affected by the gap between the coil and the metal, and more condensers are needed.

When evaluating the life of a pot the number of heats done is not always the best criterion. The time factor enters into consideration; for instance, a 150-k.v.a. set coupled to a 500-lb. furnace will take about an hour to melt, but, coupled to a 1,200-lb. unit, will take 2½ to three hours. Thus, if 60 heats were melted in the 500-lb. unit, 30 heats would be satisfactory in the larger unit, as the lining is exposed to the action of molten steel for a longer period of time. Perhaps the best test is the ratio of tons of steel melted to hundredweights of refractory used.

A poor grade of refractory will rapidly wear away by the combined action of oxide penetration and erosion due to the swirling of the metal, but sudden "runners" are almost always due to bad pot-making.

When, for teeming purposes, the furnace is tilted through an angle of 100°, this thin and mechanically-weak lining is supporting a comparatively heavy weight of metal, and must not be subjected to any undue stresses. The importance of rigidity cannot, therefore, be too strongly emphasised, as no doubt many refractory makers have taken undue blame for faults which were not theirs.

Electrodes and Welding Rods

Electrodes and welding rods for welding manganese steel and other steels are discussed in a brochure published by Hadfields Ltd., Sheffield. Information is given about rods which are manufactured to provide an ideal material for restoring worn or damaged parts of articles made in manganese or other austenitic steels of that type, extending the effective life of such articles over a long additional period at small expense, and avoiding the cost of delay of replacement. Various types of electrodes and welding rods are discussed in an informative manner. Copies are available on application to Hadfields Ltd.

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* See *Magnesium, Magnesite and Dolomite*, published by the Imperial Institute Mineral Resources Department, 1939.

Flue Gases from Heat-Treatment Furnaces

By O. G. Pamely-Evans, B.Sc., A.I.C.

Means for the control and conditioning of flue gases from heat-treatment furnaces are outlined; instrumentation is suggested which will allow close watch to be kept on them, so that even varying weather conditions will be indicated.

AT the very outset of a consideration of flue conditions in heat-treatment furnaces we must make a sharp division between muffle furnaces and those furnaces in which combustion is, or the products of combustion are, actually in contact with the charge to be heated. Muffle furnaces will yield flue gases which will be solely the waste products from combustion which has taken place merely as a source of heat, whereas the properties of flue gases from the other group of furnaces will be functions of the conditions which the atmosphere in the furnace has had to produce, reducing, carburizing, oxidizing, etc.

We will assume that the flues are reasonably air-tight (having, if necessary, been filled with silicate of soda, or other material), and proceed to a consideration, firstly of those attached to a muffle furnace.

The gases will be examined under two heads—physically and chemically. Physical measurements include those of temperature, pressure and velocity. A knowledge of the thermal capacity of the gases is also essential for any efficiency calculations, and the velocity measurements, by pilot tube will tell us if the flow is orderly or turbulent, and hence indicate the procedure necessary for sampling. The pressure should always be a negative (*i.e.*, less than atmospheric) one if possible, even in the cases, now almost universal, of forced-draught furnaces; that is, the stack, or exhausting fan, should never be working at over full designed capacity. In cases of pressure in the flues differing little from atmospheric pressure, change in meteorological conditions may reverse the flue conditions, upsetting combustion back in the furnace.

The temperature of the flue gases is quite an important point, which is, strangely enough, often overlooked. Too high a flue gas temperature is an obvious mark of inefficiency —and may be related to too high a flue-gas velocity, insufficient heat being left in the furnace. Otherwise it may be a sign of "after-combustion" of gaseous fuel or fuel products in the flue—again a matter to be looked into, both from the point of view of velocity of combustibles through the combustion zone and of flue-gas analysis.

If the gases appear to be exceptionally cool, again we may expect faults. Possibly air-leaks into the flue—or, possibly, an eddy at the point of measurement—and if the air-leak is sufficiently far back—say, in the furnace—it may be actually cooling the charge—a fact which, however, would have been immediately apparent to the furnace operator. Finally, in the case of a furnace fired on cold gas, too cool a flue-gas may show presence of excess gas, the flame temperature having fallen too low for combustion to be completed, or too little air for complete combustion having been admitted, with the consequent cooling effect of the draught of excess cold gas.

The chemical analysis of the flue gases is just as important a routine matter as the physical observations outlined above. It may be performed continuously and automatically by the use of CO_2 and/or CO recorders, but, whilst this is a very useful guide, it is only a partial analysis, and any indication of irregularity by such instruments should be followed by proper analysis with Orsat, Haldane, or other suitable apparatus.

Excess CO, or excess oxygen are signs of wrong combustion, as also is free H_2 (though this latter would only occur in exceptional cases).

Thus, CO_2 alone, recorded, may show, by a falling-off from its maximum, combustion faults or air-leaks. The basic equation

$$C + O_2 \longrightarrow CO_2$$

for combustion of carbon shows that the volumetric percentage of CO_2 in the flue gases can *never* be greater than that of oxygen in the air (*circa* 21%), whether combustion takes place in one stage (as coal in a furnace); or, two—as gasification of coal in a gas-producer, giving a mixture of CO, CO_2, H_2 and N_2, which is later burned in the furnace—or more stages. In the case of blast-furnace gas, however, the content of CO and CO_2 before combustion is higher than would seem possible from the basic equation above, and the burnt gases from the combustion of blast-furnace gas often contain up to 25% CO_2.

The excess comes from the decomposition of the limestone charged into the furnaces.

$$Ca\ CO_3 \longrightarrow Ca\ O + CO_2$$

CO_2 meters may be physical (dependent upon thermal capacity, density, or viscosity), or chemical (absorption by caustic alkali) in action.

The first type suffer inaccuracy from variations in other components of the flue gas besides CO_2—chiefly water-vapour, which has a high thermal capacity, whence small changes in its concentration can make the CO_2 reading quire unreliable; and the chemical type, unless specially adapted, gives inaccurate readings, if the SO_2 contents of the gas varies—as by firing with a different quality coal or gas. On the whole, the chemical type gives the best results, but needs far more care, and more safeguards such as dust-traps, sulphur-removers, CO_2-free water supply, etc. than the physical.

A CO recorder is an additional refinement which indicates which way the wrong combustion shown by a drop in CO_2 percentage is occurring excess air or too little.

Thus instrumentation of the flues of a muffle furnace may consist, in the ideal case, of a manometer, pilot tube and differential manometer, temperature recorder or indicator, CO_2 and CO recorders or indicators. With such equipment combustion conditions back in the furnace may be set to whatever state desired, and any deviations, faults, leaks, or irregularities of any kind instantly shown.

The case of a non-muffle furnace is similar up to a point —but in the flue gases from such, whether reverberatory or modern gas-fired, the gases may not be examined solely to give evidence of complete combustion.

The combustion may be set deliberately to give a reducing atmosphere—which would be shown on the CO meter, envisaged above as attached to the flue of a muffled furnace, were it used on the furnace in question—or the burners may be set to give a layer of soot over the charge. Possibly an oxidising atmosphere (as used to burn off decarburised layers in steel heating) may be used. Again, the gases may very likely be contaminated by the metal heated,—scale, oxide, sulphur, moisture, all manner of impurities, volatile and also carried because finely divided, may come over into the flues (cf. an ore sintering plant), and upset measurements and dimensions of the flue, even.

Where recuperators are used, the physical and chemical properties of the flue gases circulating around the air or gas-supply tubes (never the other way—flue gases in central tubes surrounded by fuel gas or air—which leads to less effective heating) are important. After combustion, or a hot oxidizing or even decarburizing mixture of gases may cause a development of leaks, and mixture of fresh and flue gases. A manometer on the forced-draught air, or on the gas main to the recuperator may show the occurrence of such a leak.

Sometimes old fire-tube boilers are used as such heat-exchangers, and in the case of a plant not specifically designed for its job, such as this, extra care must be exercised in the observations taken. If regenerators packed loosely with fire-brick are used, the carry-over of solid matter, as well as the chemical characteristics of the flue-gases, if of great importance. Pressure (or draught) measurements will show at what points obstructions, whether by deposits from the gas, or slagging of the brick, are occurring, and hence indicate zones to be by-passed if continuous working is to be maintained.

Dampers, whether at the stack or furnace exit, or both, have a very great influence on the gas condition. The damper may be a slide in a venturi-tube-like construction, or a plain butterfly-valve, or "Venetian-blind" type. Any may be manual or automatic in operation. The automatic type naturally gives the best results, provided certain conditions are observed. It must take the impulse for its operation from some function of the furnace condition—pressure of the furnace atmosphere, flue-gas velocity—rate of combustion (*i.e.*, air consumption)—but whatever the controlling factor is, it is *that* factor alone which the damper can control. Usually it is furnace atmosphere-pressure, which may be required to be just *above* that of the atmosphere, so that ingress of cold air is avoided. A figure—say 0·1" W.G. is pre-set on the controller and the damper is then automatically actuated to maintain the figure. This type of control is, however, far from fool-proof, and may well produce ill-effects under certain conditions. It is possible that a strong wind or other draught is blowing through a door or open end of a shop on to the doors of a furnace where the damper controller is set to maintain a positive pressure in the furnace. Cold air is forced through the doors and cracks—increases the furnace pressure—expands in the heat of the furnace, and further increases the pressure. The damper-controller immediately sets about opening the damper—and the result is that *more* air is drawn in—the very result that the installation was provided to avoid.

It is wise to take careful and close readings of *all* conditions before deciding to install automatic damper control.

The question of dust, scale, soot and other smokes in the flue gases is an important one. One well-known metering firm supplies a device for measuring and indicating smoke density in the flue or the stack. It consists of a lamp and a photo-electric cell, one placed on each side of the flue, the lamp being focused on to the cell.

Increase or decrease in the smoke density is reflected in current variations which deflect an indicating pointer on a scale or pen on a chart. Warning signals can be arranged to go off if the smoke becomes too dense. Thus efficiency of a dust-catcher or other device can be continuously checked, and need for cleansing or renewal indicated.

The above is an outline of means for control and conditioning of flue gases, and, together with a large number of sample holes or points (none of which should be near to the damper or other place where air ingress is possible), the instrumentation suggested will allow such close watch to be kept on them that even varying weather conditions will be appreciably indicated—through stack capacity varying with air density, etc.—but it must be pointed out that such an installation, *en bloc*, would be expensive, and the return on the capital outlay small. Individual items, however, may well repay their installation on plants that merit their use.

Limitation of Home Supplies of Machinery and Plant

Under the Machinery and Plant (Control) (No. 2) Order, 1940 (S.R. and O., 1940, No. 1,363, price 1d.), the acquisition and disposal of machinery and plant and parts thereof of classes specified in a list from or by a United Kingdom manufacturer of any such machinery or plant is prohibited, except under licence issued by the Board of Trade (whether or not the actual machinery or plant or parts thereof to be supplied are manufactured by him). The list is published in the *Board of Trade Journal.*

All persons who propose to acquire machinery or plant or parts thereof of any of the specified classes from a United Kingdom manufacturer must, therefore, first obtain a supply licence from the Industrial Supplies Department (Machinery Licences Division), Board of Trade, 25, Southampton Buildings, London, W.C. 2, and no manufacturer may dispose or agree to dispose of machinery or plant or parts without first ascertaining that the person to be supplied has already obtained a licence for the supply from him of that machinery or plant or parts. Machinery or plant or parts for direct delivery (*a*) to an overseas market or (*b*) to or to the order of a Government Department or (*c*) to another manufacturer of the specified machinery and plant is, however, exempt from these requirements. There is also an exemption for repair parts. "Repair" parts are those required for servicing or effecting running repairs to maintain a machine or plant in its existing use, and are not such as will provide parts or motions capable (*a*) of modifying the mode of operation of the machine or plant or (*b*) of effecting the rebuilding, refitting, recruitment or remodelling of the whole or part of the machine or plant.

Persons desiring to acquire machinery or plant or parts from manufacturers are warned that they must not enter into contracts for machinery or plant or parts without first obtaining a licence. Similarly, machinery manufacturers must not book orders for machinery or plant or parts until they know that the person to be supplied has obtained the necessary supply licence. The Order applies also to second-hand and imported machinery, plant and parts. Each supply licence has attached to it a certificate, which should be obtained by the machinery manufacturer and held carefully by him until the machinery or plant or parts have been delivered, when the certificate should be returned to the Industrial Supplies Department (Machinery Licences Division), Board of Trade, 25, Southampton Buildings, Chancery Lane, London, W.C. 2.

It should be noted that the supply of machinery or plant or parts of the classes specified under contracts made prior to the date of the Order is not exempted from the licensing regulations and persons who have already placed orders for such supplies should make their applications for licences without delay. If a person delays making an application for a supply licence for machinery or plant or parts which he has already ordered, the fact that the machinery or plant or parts have been partly or wholly completed at the date of the application will not influence the Department in the direction of granting a licence which they would otherwise refuse.

Applications for licences should be addressed to the Industrial Supplies Department (Machinery Licences Division), Board of Trade, 25, Southampton Buildings, London, W.C. 2, and they must be made on forms which are obtainable from that Department.

Errata

In the abstract of the paper on "Factors Influencing the Formation of a smooth Coating of Tin on Copper by Hot Dipping," on page 130 for August issue, the name of one of the authors, Dr. Bruce Chalmers, in the third line, is misspelt, and in the following line the word "finest" should obviously be "finish."

Some Low-Alloy Steels

By William Ashcroft

Plain carbon steels may be deficient in strength, toughness, or shock-resisting powers; they may not possess desirable corrosion-resisting properties, strength at high temperatures, or do not permit a necessary reduction in weight. The engineer must, therefore, use other steels which give him the required properties, requirements that are met by alloy steels. The bulk of these are low-alloy steels, some of which are briefly discussed and reference is made to some of their outstanding properties and to purposes for which they are applied.

IN many respects the more exacting engineering demands of recent years have limited the application of carbon steels; thus, for long life at high and low temperatures, equal strength and toughness with decreased weight, high fatigue values under severe service and high resistance to corrosion, alloy steels have become essential to the engineer. Apart from effecting performances unattainable with carbon steels, the utilisation of alloy steels depends largely upon the economical advantages resulting from their longer life, causing fewer breakdowns and repairs. In practically every field of production applications have been found in which alloy steels have proved superior to carbon steel, and an economical proposition; their additional cost in comparison with carbon steel is more than offset by their longer life in service.

Great improvements have been effected in the manufacture and subsequent heat-treatment of carbon steel, resulting in greater uniformity, but there are limitations to the improvement in properties obtained by heat-treatment which can only be overcome by the action of certain alloying elements. It is well known that the characteristic properties of carbon steel and their alteration by heat-treatment depend upon the condition in which the carbon exists in the material. In one condition the carbon is present as carbide of iron embedded in crystals of iron; this is the more common condition, and is represented by the pearlitic steels which are largely used for structural work, and components in which a moderate degree of strength and toughness is required. In another condition the carbon is dissolved in the alpha variety of iron and produces the martensitic steels; this condition is obtained by the rapid cooling of carbon steel and is exceedingly hard, but by suitable tempering the degree of hardness can be controlled. A third condition is not less important—that in which the carbon is completely dissolved in the gamma variety of iron, the so-called austenitic steels, which is found in the presence of suitable amounts of certain alloying elements. These steels are harder and tougher than pearlitic steels of similar composition and have not the intense hardness associated with martensitic steels.

The capacity of steels for existing in the pearlitic, martensitic, or austenitic conditions is influenced by the action of alloying elements; they may effect the transformation of the steels or they may promote specific characteristics. The effect of alloying elements on the transformation of steels is of vital importance and is responsible for the most extensive uses of alloy steels in practice. It is well known, for instance, that while it is comparatively easy to harden a small section of carbon steel and produce its hardest condition it becomes increasingly difficult as the sectional area becomes greater; not only do difficulties arise in obtaining the desired hardened condition in larger mass, but warping and cracking is likely to occur, especially with components that are somewhat complicated in design, due to stresses set up by water quenching. These difficulties are due to the fact that steel must be cooled rapidly through the critical point if the hard condition is to be obtained, and unless this condition results the process of heat-treatment has little or no value. With ordinary carbon steels it is difficult to obtain the completely hardened condition throughout a component which exceeds an inch in thickness, and if the manganese content is low even this small size may be too large to enable complete hardening to be obtained. With still larger sections the ratio of cooling which can be obtained, even by the use of water quenching, have not the required critical quenching velocity and have little effect on the structure or properties of the steel.

It is generally recognised that steel parts are not usually required in the fully hardened condition, but it should be remembered that it is impossible to obtain the best combination of mechanical properties unless full hardening has been obtained during the quenching process. Thus, in order to obtain the fullest possible advantages from the heat-treatment of steels, some method must be adopted which will reduce their critical cooling velocity for hardening and many alloying elements used in steel manufacture confer this property, enabling a fully hardened condition to be obtained in large masses. But even when an alloy steel is not essential to obtain complete hardening by quenching, the fact that slower rates of cooling can be used, by quenching in oil or in air, reduce the risks associated with the more drastic water-quenching.

The degree of hardening which can be produced in a steel depends primarily on the carbon content, but the ease with which it can be produced varies considerably between one steel and another and depends upon other elements present in the steel. Manganese, chromium, molybdenum, and nickel are all effective in facilitating hardening, because when they are present in steels slower cooling rates are used to promote the hardened condition. When sufficient of the alloy is present, the normal cooling in air, even of large masses, may be adequate to give the hardened condition—for instance, a 0·3% carbon steel containing 3·5 to 5% nickel and 1 to 1·5% chromium is typical of air-hardening steels in common use; some of the manganese steels—those containing 5 to 10% manganese with carbon 0·4%—also become martensitic in structure when cooled at ordinary rates without quenching; 8 to 20% nickel produces a similar effect. Tungsten, cobalt, and vanadium have a similar effect on steel, though not so intense; silicon, on the other hand, makes the suppression of normal transformation more difficult.

In practice, the number of elements added to steel is relatively small, only about seven or eight being in general use; it will be appreciated, however, that not only is there a wide range due to varying the carbon contents and also the contents of a particular alloy, but there are many combinations of alloying elements used together; consequently the number of steels of different composition, and, of course, different properties, is very large. It is not possible to give a detailed consideration of all these steels in this article, but it will be of interest to give brief particulars of some of the more commonly used low-alloy steels, to refer to their outstanding properties and the purposes for which they are usually applied.

Carbon-Manganese Steels

Better melting methods and the production of cleaner and better steels have placed the carbon-manganese steels in a deservedly higher plane. They not only fill a wide range of alloy steel applications, but are relatively cheap.

With a proper relation of carbon to manganese content, these steels are superior to carbon steels of similar carbon content, and at least equal to the low nickel-chromium steels in many respects. Considerable attention has been given to these steels, and as a result of much research a useful range has been developed. The chief alloying element in these steels is manganese, amounting to about 1·5%. The corresponding mechanical properties, in most respects, are intermediate between the plain carbon and more fully alloyed steels, though in one respect, notably as regards the notched bar impact tests results, some of these steels are actually superior to fully alloyed steels.

It is frequently assumed that the carbon-manganese steels are brittle on treatment, but with proper control of heating, forging, and finishing temperatures, and saturation on heating for hardening, followed by a rate of cooling determined by the carbon-manganese content in relation to the mass factors, these steels are not more sensitive than other steels used quite freely for similar purposes. In the low-carbon range, for instance, containing 0·1 to 0·15% carbon and 1·4 to 1·8% manganese, carbon-manganese steel, apart from its use as a case-hardening steel, may be used for all purposes where a strength of about 35 tons per sq. in., combined with a high Izod value, is required. Used for gearwheels, camshafts, pins, levers, spindles, and other general engineering work, this steel gives good service. With slightly increased carbon content of, say, 0·25 to 0·3%, a minimum tensile strength of 44 tons per sq. in. is obtained after being oil-quenched and tempered, and an Izod value of 50 ft.-lbs., while the strength is further increased, with no appreciable difference in impact value, by the addition of a small percentage of molybdenum. These steels are finding increasing application in railway and general engineering work, for such purposes as crankshafts, connecting rods, tramcar and railway axles, armature spindles, etc.

An interesting development in this range is a steel containing 0·25 to 0·35% carbon, 1·4 to 1·8% manganese, 0·25 to 0·3% molybdenum, and 0·5 to 0·7% nickel. It is a medium tensile steel having a remarkable combination of properties; it is used for highly stressed moving parts; for stampings of various kinds, such as front axles for automobiles. It may be used for any purpose within its range of tensile strength—i.e., 40 to 50 tons per sq. in.

Low-Chromium Steels

The addition of comparatively small percentages of chromium to a carbon steel produces fineness of structure and gives increased strength with little corresponding loss in toughness and ductility, and the increase in cost due to the chromium addition is so slight in comparison with the gain in strength and wearing capacity that the advantages of low-chromium steels are becoming more and more apparent. After heat-treatment and dependent upon the size of the section, an increase of 15 to 20% in tensile strength and elastic limit, with small loss of ductility, over straight carbon steels with the same carbon-manganese content, is obtained with a steel containing 0·5 to 0·7% chromium. In the hardened condition it gives excellent service for wearing surfaces, such as gearwheels, discs, mandrels, etc., and it is especially suitable for surface hardening.

Care must be exercised in the heat-treatment of low-chromium steels to obtain the most satisfactory results, as they do not permit the same latitude in treatment as some other alloy steels; for this reason chromium is often associated with such elements as nickel, molybdenum, or vanadium. The chromium-molybdenum steels, for instance, within the range of 0·25 to 0·45% carbon, 0·8 to 1·1% chromium, and 0·25 to 0·45% molybdenum provide steels which by suitable heat-treatment have physical properties that conform with alloy steels containing more costly alloys. In the heat-treated condition they are readily machinable and are useful for mass production purposes. Oil-hardened at 850° C., followed by tempering in air from 600°–650° C., a maximum stress of 50–55 tons per sq. in. may be obtained in 3-in. sections, with an Izod test of 70–40 ft.-lbs. By reducing the tempering temperature, the maximum stress may be increased. These steels come between the manganese-molybdenum and the high-tensile steels and are used for tabular construction, particularly aircraft tubes. They respond to a simple air-hardening or toughening treatment after welding, due to the combined presence of chromium and molybdenum.

Nickel Steels

Originally added to give increased strength and toughness over that obtained in the ordinary rolled structural steel, the development and possibilities of heat-treatment have greatly enhanced the value of nickel, and despite the commercial application of many other alloys, nickel steels continue to find increasing applications. The advantages of nickel is too well known to need repetition here, but it is noteworthy that a steel with about 0·25% carbon and about 3% nickel has a tensile strength equivalent to a 0·45% carbon steel, a proporticnately greater elastic limit, and the advantageous ductility of the lower carbon steel. The more common of the nickel steels are those containing 3 to 3·5% nickel; they cover a very wide range of applications, of which special mention may be made to crankshafts, axles, connecting rods, and forgings of all kinds. Nickel tends to promote the graphitisation of the carbide of iron and, to reduce this tendency, straight nickel steels usually contain relatively higher manganese contents. It must be remembered, of course, that the marked improvement in physical characteristics of these steels, in the 5% nickel steels, as with other alloy steels, depends upon suitable heat-treatment.

The improvement in ductility and toughness conferred by nickel and the increased strength, surface hardness, and depth-hardening obtained from the addition of chromium are combined in the nickel-chromium steels, and a proper combination of the two alloys will accentuate the density of structure, reliability, and responsiveness to heat-treatment, as well as conferring distinctive properties not characteristic of either alloy when used alone. The mechanical properties of these alloys my be varied according to the respective additions of nickel and chromium, but research and experience has shown that a ratio exists between the percentage of nickel and chromium which, for general purposes, will give the most desirable combination of mechanical properties, but, by slight variations in the nickel and chromium contents, certain physical properties may be increased; thus, a very wide range of high-duty properties can be obtained from these steels in the heat-treated condition.

The low-carbon nickel-chromium steel containing 0·18 to 0·25% carbon, 3 to 3·75% nickel, and 0·4 to 0·8% chromium is used for highly stressed parts, where carbon steels are inadequate; among its applications may be mentioned crankshafts, shafts, axles, bolts, and studs. An improved grade with carbon ranging from 0·25 to 0·35%, with similar nickel and chromium contents, includes a small percentage of molybdenum which has a definite effect on the density and permits the use of higher drawing temperatures to develop the mechanical properties of the steel. This steel has a higher ratio of elastic limit to tensile strength in comparison with a similar steel without molybdenum.

Some nickel-chromium steels have been specially developed for gearwheels; within the range of 0·28 to 0·32% carbon, 3 to 3·75% nickel, and 0·55 to 0·7% chromium, these steels have high strength, when properly hardened and tempered, and a minimum Brinell hardness of 430; their particular field of application is for shock-resisting gears, etc., where great durability and strength are essential with simple treatment. For highly stressed shafts, tubes, turn-buckles, gears, etc., the air-hardening nickel-chromium steels give tensile test results of 100 tons per sq. in. The addition of molybdenum in some grades results in a steel which is less sensitive to unavoidable variations in heat-treatment, and under similar treatment gives a distinctly higher impact value.

Molybdenum Steels

As has been already noted, molybdenum, together with other alloying elements, is a useful addition to steels. But molybdenum additions are also made with advantage to plain carbon steels, especially is this true of steels for high-temperature purposes. The rise in operating temperatures of steam-generating plant to obtain greater efficiency has necessitated the development of materials of greater strength at high temperatures than is possible with the low-carbon steel previously used. For such purposes a steel with a maximum of 0·2% carbon and containing 0·3 to 1% molybdenum provides a valuable range. Investigations have shown that the addition of molybdenum has a pronounced effect in reducing the loss of strength and the rate of creep at high temperatures. Additions of 0·5% or over have been found to double the strength of a carbon steel at elevated temperatures and to reduce effectively the rate of creep under the same conditions. As a result of this property, molybdenum-containing steels are largely employed in such parts as turbine covers, rotors, steam cylinders, valves, boilers, etc., which operate at temperatures of 400° C. and more.

Molybdenum steels also have useful applications at normal temperatures. Increasing percentages of molybdenum increase the tensile strength, yield-point, and elastic limit of a plain carbon steel, although as a result the elongation, reduction of area, and impact value are reduced. They are suitable, therefore, where high strength and resistance to wear are required, and where ductility is of secondary importance. By varying the tempering temperature of a carbon-molybdenum steel an improved range of properties can be obtained, compared with a carbon steel of equal carbon content; a 0·3% carbon steel, for instance, containing 0·5% molybdenum, has an elastic limit of 34 tons per sq. in. and a yield-point of 35·6 tons per sq. in., compared with a carbon steel of similar carbon content of 15 and 18·5 tons per sq. in. respectively.

The addition of about 0·4% copper to a low carbon-molybdenum steel greatly improves the steel's resistance to atmospheric corrosion. This type of steel is used in large tonnages for structural purposes, where the steel is exposed to the atmosphere, and since it is also effective in high-temperature applications it is used for boiler and superheater tubes, boiler drums, and similar parts.

Nickel-Chromium-Molybdenum Steels

The beneficial effects of molybdenum on nickel-chromium steels is well known; not only does it increase the toughness, but it diminishes the mass effect in hardening and reduces the possibility of temper brittleness. In correctly adjusted proportions nickel-chromium-molybdenum steels may be used at high steam temperatures for long periods without the tendency to develop shock brittleness or the deterioration of other properties. There are several grades of these steels, and each is developed to cover a range of applications for which their valuable properties fit them. These may be grouped in two types, the oil-and-air hardening and the case-hardening types. In the former, the range covers materials containing 0·25 to 0·45% carbon, 1 to 4·5% nickel, 0·5 to 1·8% chromium, and 0·25 to 1% molybdenum. The principal alloy steels of this type contain 2 to 3% nickel and 0·5 to 0·7% molybdenum within the range of carbon and chromium contents already mentioned. When heat-treated to give a maximum stress of 60 to 65 tons per sq. in., although this is readily increased by adjusting the tempering temperature, this range provides a very wide field of usefulness, and advantage may be taken of the high physical properties to reduce weight. It is applied to components that are subjected not only to high stress, but also to extremely severe wear. Usually the carbon content is governed by the size or mass of the part; in general, higher carbon steel is used for larger parts, but these steels have a very small mass effect and considerable resistance to creep at elevated temperatures.

The case-hardening type generally contains 4·5% nickel, 1·5% chromium, and 0·35% molybdenum. This steel is used where exceptionally high core strength is required, such as certain types of gears which are subjected to very severe service. With suitable treatment a core strength of 90 tons per sq. in. tensile can be obtained with an impact value of 25 ft.-lbs.

It has only been possible to deal briefly with some of the more commonly used alloy steels, and although some reference has been made to their applications it will be appreciated that within the range covered there are an infinite variety of physical properties which meet the more exacting demands of the engineer under widely different conditions of service. These steels are more costly than carbon steels, but, providing a wise selection is made and the steel is subjected to the proper treatment to develop the properties desired, the service obtained will more than compensate for the additional first cost. Not infrequently, the initial cost of the steel is a very minor detail in the total cost of the part produced, and when increased service is considered the use of the more expensive alloy steel is usually economically cheap.

Copper-Smelting Works in Central Urals.

THE Central Urals Copper Smelting Works, the largest of its kind in the U.S.S.R., situated in the heart of the Urals mining industry at Revda, 25 miles from Sverdlovsk, was recently put into operation. Equipped with the most up-to-date machinery, the plant occupies a place in the Soviet non-ferrous metal industry comparable to that of the Nagbitogorsk Works in the Soviet iron and steel industry. The new plant has a capacity one and a half times greater than the entire output of copper in Russia in 1913.

Copper ore will be supplied to the new plant by the Degtyarsk pyrites deposits, which contain almost half the copper ore in the Urals. Unlike other Soviet copper producers, this plant uses coal-dust for firing the reverberatory furnaces, which is considerably cheaper than using oil.

A reverberatory furnace in the plant, 105 ft. long and 26¼ ft. wide, is one of the most improved type in the Soviet Union, and is the work of Soviet builders who took advantage of American and Soviet experience in this field. The charge of pyritic ore and slagging minerals is brought to the furnace by transporters and elevators, and the proportions are weighed and mixed automatically. Manual labour has been reduced to the point where the workers have only to handle the control and measuring devices, and the automatic scales.

The converters of this plant are also outstanding: they are the first in the Soviet Union to be provided with roller bearings, which make it easy to turn the entire unit. The converters also have an original automatic device for emergencies, a "charge rejector," for cases when the blast fails. The converters are charged by powerful overhead cranes able to lift a 75-ton load. From there the copper matte is poured into ingots, and after it has cooled off is mechanically loaded into railway wagons.

The plant has a well-appointed concentration factory, as well as a mechanical repair shop equipped for making not only spare parts but also entire machines. Two chimneys, 394 ft. and 492 ft. high, carry away the sulphur-containing gases. These chimneys are situated some distance from the factory and the town, and a special pipe-line carries the gases to them. The plant's equipment, it is claimed, makes it possible to extract 95% of the metal from the ore.

Mr. A. J. Newman has been appointed Director of Machine Tools with responsibility for the supply of machine tools to the Ministry of Aircraft Production.

Beryllium and Some of its Aluminium Alloys

During recent years methods have been developed for the commercial production of relatively pure beryllium metal in solid form as distinct from the more usual flake, and a product has been obtained with a purity varying, according to the care employed, from a guaranteed minimum of 96% to as high as 99·94%. The properties of this pure metal and of some of the aluminium alloys prepared with it have been investigated by C. B. Sawyer and B. Kjellgren*, both of whom have had a large part in its production.

For the purpose of the investigation, a metal was selected containing about 99·5% of beryllium, the impurities being aluminium, iron, magnesium, carbon and silicon. A tensile test on a chill cast bar gave an ultimate breaking stress of 9·37 tons per sq. in. without any measurable elongation, and an acoustic determination of the modulus of elasticity gave this property as 42·3 by 10^6 lbs. per sq. in. The Brinell hardness of the material was 114 with a 1,500-kg. load, and the impression on a highly-polished surface after etching showed cracks both inter- and intra-crystalline. A preliminary determination of the electrical conductivity in the cast condition gave the result of 38·9%, that of copper at about 30° C., the coefficient of thermal expansion was determined as 0·0000133 per ° C. at 20° to 200° C., and the mean specific heat as 0·475 calories per gram per ° C. between 32° and 100° C.

A ⅜-in. cast bar was forged at 900° to 1,000° C. into a bar of about 0·36 in. diameter. The electrical conductivity of this forged material was determined as 42·4%, that of copper at 29° C. The physical properties as forged and after annealing in hydrogen at 1,000° C. are given in Table I.

Table I.

	Forged.	Forged and Annealed.
Tensile Properties.		
Ultimate strength, tons per sq. in.	13·33	12·05
Elongation	—	—
Reduction of area	—	—
Modulus of elasticity, lb. per sq. in.	$40{\cdot}0 \times 10^6$	$36{\cdot}8 \times 10^6$
Compressive Properties.		
Yield strength, tons per sq. in	15·54	—
Modulus of elasticity, lb. per sq. in	$42{\cdot}0 \times 10^6$	—
Shearing strength, tons per sq. in.	17·23	—
Density	1·844	—

The velocity of sound in this beryllium was computed to be 12,600 metres per sec. or 41,300 ft. per sec., or 2·1/2 times that of steel, and this high velocity together with its apparent permanency suggests numerous acoustic applications such as for high-frequency standards. A small sample of this 99·5% beryllium was given a metallographic polish, and its total relatively in white light determined to lie between 52 and 55%. This compares with about 55% for polished chromium, but is notably less than the 80% obtained with polished aluminium. The polished surface also appeared to be permanent, and this factor combined with its low density of 1·844, its high elastic modulus 40·0 by 10^6, and its fair electrical (and thermal) conductivity indicated its use for mirrors both oscillating and stationary. As beryllium is also 17 times as penetrable by X-rays as is aluminium, and is not adversely affected by them, it may also be used in X-ray work for windows to filter out strong or reflected electrons.

A chill-cast aluminium-beryllium alloy containing approximately 28% aluminium and the remainder 99·5% beryllium, had a yield point of 8·48 tons per sq. in., a tensile strength of 11·16 tons per sq. in. and elongation of 3%. Other properties were modulus of elasticity, 29·0 by 10^6 lb. per sq. in., Brinell hardness 86, specific gravity 2·03, and coefficient of expansion per deg. C. 0·0000151. Mico-examination showed the structure to consist of aluminium-beryllium eutectic (0·87%) at the boundaries of beryllium grains. It was also found that beryllium can contain magnesium in alloy form up to at least 1%, but that beryllium solidifying in the neighbourhood of 1,300° C. appears to reject higher percentages of magnesium as a vapour. Beryllium added to magnesium base alloys, containing 8% aluminium, decreases the grain size, hinders oxidation while melting and increases the resistance to corrosion by sea water, this latter effect being brought about with amounts even so small as 0·005% beryllium. Similarly, beryllium in amounts from 0·005% to 0·6% may be used for refinement in aluminium base alloys.

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* *Metals and Alloys*, 1940, vol. II, No. 6, pp 163-167.

The Manufacture of Steel by the Perrin Process

(*Continued from page* 156)

dephosphorised blows will be required to fill each of the 100-ton open-hearth furnaces, from which the equivalent weight of about two blows will normally be tapped as finished steel into a 50-ton casting ladle, leaving in the furnace approximately half the quantity of metal charged, to which two dephosphorised blows will be added and the process repeated. Ingots of various weights will be cast from acid open-hearth steel in accordance with the requirements of the wheel, tyre and axle plant which is being erected at the same time as the Perrin process plant.

As it will therefore be necessary at times to dephosphorise blown metal containing considerable percentages of carbon, experiments were carried out to ascertain how far this was possible. Particulars of one such experiment are given in the paper as an example. The result indicated that the dephosphorisation of iron, even in the presence of a high percentage of carbon, could be successfully accomplished, providing that there was not too much silicon present in the iron. Thus, it is seen how flexible is the slag dephosphorising process.

In summing up the possibilities of the Perrin process as applicable to the conditions at Jamshedpur, any possible value of the used dephosphorising slag as an artificial fertiliser has been ruled out of consideration, owing to its contamination with acid Bessemer slag, and the necessity to use fluorspar to obtain the essential fluidity of the slag. Moreover, it is evident that on account of the loss of phosphorus by volatilisation during blowing, there is an insufficient percentage of this element in the blown metal to yield a sufficiently high P_2O_5 content of the slag, even when the following precautions are taken :—

(*a*) The use of a minimum percentage of slag for dephosphorisation ;

(*b*) The prevention, as much as possible, of the acid Bessemer slag from entering the casting ladle ;

(*c*) The lining of the casting ladle with basic refractories, the extra expenditure on which would, of course, offset to a considerable extent the possible sale value of the used slag.

Rolling-Mill Bearings

One of the greatest problems in connection with the operation of rolling-mills has been the lubrication of roll bearings. Even in the days of the old slow-speed mills, the bearing was a constant source of trouble and expense, and hot bearings were a common occurrence, and only by the copious application of water to the roll necks and to the rolls themselves could the heat generated be reasonably dissipated. With the development of high rolling speeds efforts have been made, with varying degrees of success, to reduce the huge wastage of power. A great advance came with the development of the Robertson "Flood" Lubrication roller bearing, and to-day comparative tests show the remarkable efficiency of this system. An informative brochure on the subject has been published by W. H. A. Robertson and Co. Ltd., Bedford, copies of which may be obtained on application.

Influence of Titanium on Some Properties of Chromium-Molybdenum Steel

The results of some experiments on chromium-molydenum tube steel are given. The experiments were undertaken to determine whether small additions of titanium would improve its ductility and weldability without impairing other useful properties. The effects of higher manganese and of copper additions were also investigated.

IN view of the difficulties which have been encountered occasionally in welding chromium-molybdenum steel tubing for aeroplane construction, some experiments were recently undertaken by G. F. Comstock* to determine whether small additions of titanium to steel containing 0·33% carbon, 1% chromium, and 0·2% molybdenum would improve its ductility and weldability without impairing any other useful properties. Since titanium additions to other steels of somewhat similar composition have been found to reduce the strength of such steels, the effects of higher manganese and of copper additions were also investigated in order to determine whether such changes would counteract any reduction in strength, while still permitting titanium to improve the ductility and weldability.

Eight heats of steel were made for the investigation in a 17-lb. induction furnace, and the ingots were rolled to 7 to 8 in. diameter rounds. Each ingot contained 0·33 to 0·34% carbon, 0·97 to 1·04% chromium, about 0·2% molybdenum, 0·18 to 0·25% silicon, 0·019% phosphorus, and 0·026% sulphur. The manganese, titanium and, copper contents are given in Table I.

TABLE 1.

Heat.	Manganese.	Titanium.	Copper.
1	0·55	0·006	—
2	0·60	0·039	—
3	0·58	0·068	—
4	0·56	0·104	—
5	0·48	0·150	—
6	0·85	0·093	—
7	0·48	0·090	0·31
8	0·54	0·098	0·78

The greater part of the $\frac{7}{8}$-in. round bars were cut into short lengths which were normalised at 900° and 950° C., and machined to standard tensile and impact test-pieces. Two tensile test-bars were normalised at each temperature and both of those normalised at 900° C., and one of those normalised at 950° C. were tested without further treatment, while one of the test-bars normalised at 950° C was tempered at 200° C. for 16 hours to relieve stress before testing. None of the impact-test specimens were stress relieved, and the impact values given are averaged from four tests.

Titanium additions, even as little as 0·039%, decreased the yield strength and raised the impact resistance, but more than 0·068% of titanium was required to affect appreciably the tensile strength and ductility. With the manganese increased from 0·56 to 0·85%, the yield point of the steel containing 0·093 to 0·104% titanium was lowered to the value obtained for the non-titanium steel (0·006% titanium), while the tensile strength was higher, the ductility about the same, and the impact strength equal to that of the low titanium and lower manganese steels, or two or three times as high as in the non-titanium steel. Copper additions were not so advantageous as increasing the manganese content, since when the yield point was raised sufficiently by copper, the ductility and impact strength decreased.

Normalising at 950° C., instead of 900° C. improved the yield and tensile strength of all the steels, but did not improve the elongation or impact resistance. The low-temperature tempering after normalising at 950° C. raised the yield point of the steels containing copper, but had a slight softening effect on the others, decreasing some of the strengths a little and improving the ductility. Micro-examination of all the steels after both heat-treatments showed the steels containing titanium to have a much less angular structure than the non-titanium steel.

In view of the beneficial effects of about 0·1% of titanium and the other satisfactory properties found when the manganese content of 1% chromium, 0·2% molybdenum steel was raised to 0·85%, it was decided that welding tests should be made. The round bars of the various steels were flattened by forging to flats about 2 in. by $\frac{1}{4}$ in., and these were normalised at 900° C. The scale was then removed from one side of each piece by sand-blasting and a weld run, about 12 in. long by $\frac{7}{16}$ in. wide, was deposited lengthwise along the middle of that side. All the welding was done by the same operator, using similar electrodes, and in approximately the same time. Bend test-pieces were cut 9·5 in. long from the welded samples, measuring from the end where the weld started, and on these test-pieces the weld runs were ground flat and the sides of the test-pieces machined to give a width of 1·5 in. with the weld run in the middle. The test specimens were bent slowly in an Olsen cold-bending machine around a pin 1·5 in. diameter with the weld on the outside. None of the specimens cracked in this test, which was continued to a bend of 170°, and the bends were then flattened in a compression machine until cracks occurred outside the weld. All the steels containing titanium showed better results in this type of test than did the non-titanium steel, which was the only one to crack suddenly across both the weld and the plate at the same time. In all the others the cracks started in the welds and extended so slowly into the plates that the tests could be stopped just as the plates began to crack, but before the cracks reached the edges of the specimens. The high copper steel showed much less flattening of the bend without penetration of the cracking from the weld metal through the plate.

Cross-sections of the weld deposits cut for etching and hardness tests 9·75 in. from the start of the weld were filed smooth and etched to show the extent of the weld metal and of the hardened zone beneath. Four hardness tests were made in a straight line transversely across the section starting about the middle of the weld run. Eight additional hardness tests were made on each section in a row extending lengthwise through the base of the weld deposit, four being on one side of the cross-wise row and four on the other. The results obtained are given in Table II, in which the first of each set of four crosswise tests show the hardness of the weld deposit and the others that of the heat affected zone below it.

The last column in Table II shows the difference between the lowest and the highest reading of the base metal of each welded sample, excluding the weld metal, and thus affords a comparison of the various steels on the basis of hardening due to welding.

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* *Metals and Alloys*, 1940, Vol. 12, No. 1, pp. 21-26.

TABLE II.

No.	Rockwell C Hardness.	Hardness Range in Plate.
1	14–23–29–29	
	24–25–29–29–31–30–25–25	8
2	8–25–27–29	
	23–24–28–28–28–29–22–24	6
3	14–25–31–29	
	26–26–30–34–33–26–26–26	9
4	15–29–30–27	
	22–24–22–29–31–23–23–35	9
5	16–23–27–25	
	15–17–17–27–28–17–17–17	13
6	12–25–30–31	
	27–26–30–30–33–30–27–28	8
7	19–25–31–32	9
	28–27–28–33–34–26–27–29	9
8	22–34–35–29	
	30–32–38–36–36–34–32–33	9

The results obtained show that although the softening effect of the higher titanium contents is apparent, the hardening due to welding did not decrease proportionately with increasing titanium. The titanium steel with high manganese shows up well, and although naturally harder than the titanium steels with normal manganese, it was not hardened quite so much by the welding operation. The copper steels were harder in general, and hardened more or to a higher degree when welded. Hardness tests would probably have shown greater variations between the steels if the welded plates had been thicker.

Micro-examination showed that the structures did not differ appreciably between the steels, except in the extent of the various welded zones. The hardened zones were comparatively coarse grained, while farther from the weld runs the structure was very fine. Although the weld was sharply defined in structure, the coarse and fine zones of the plate beneath merged gradually into each other. In the higher titanium steels the coarse-grained zone was quite narrow, while in the untreated steel it was much broader.

In general in forged and normalised steels containing 1% chromium, 0·2% molybdenum, welded lengthwise, machined flat, and bent cold with the weld outside, the presence of titanium improved the bending quality, even when accompanied by higher manganese or 0·31% copper. The presence of over 0·15% of titanium produced a softer steel, but did not decrease the degree of hardening by welding.

Reviews of Current Literature

Refining Precious Metal Wastes

IT is not often that a book is written with such a wealth of detail as this book on the refining of precious metal wastes, and it may be that some readers will find it tedious on this account, but the majority who are interested in this subject will appreciate the amount of detail as evidence of the practical experience of the author, and will find the information given invaluable. After all, it must be remembered that success in the recovery of precious metals from wastes necessitates methods that will result in recovery of the maximum quantity and careful attention to detail is of major importance in securing this end.

The book is based on 24 years of experience in teaching jewellers and others how to refine their precious metal wastes; at first in contact with students at jewellery factories or dental laboratories, and later by post. In the latter case instructions were prepared to meet the individual requirements of the student and were adapted to the type of jewellery he made, the size of his shop, his own background of education or experience, and the kind of waste he happened to have on hand at the moment. Thus, it is based on these oral and written instructions, and is presented in a form which will meet the needs of many workers handling many different problems. It assumes complete inexperience on the part of the reader as far as the first part of the book is concerned, but the second part, which concludes with a discussion of the processes used by large professional refineries, is for the experienced worker.

The author gives complete instructions on how to recover and purify precious metals from jewellers' wastes, including filings; clippings; old jewellery; buttons; turnings; polishings; sweepings; old crucibles; plating, stripping and pickling solutions; wash-barrel settlings, etc.; high carat golds; white and green golds; goods containing soft solder; rolled, filled and plated goods; sterling and plated silver; gold and platinum combinations. Information is given on the recovery from dental wastes, including dentures; dental pins; grindings and sweepings; solders and alloys; wrought and casting golds; palladium-gold alloys; high-melting platinum-gold alloys; and amalgams. Recovery from photographers' and other wastes is included, such as mirror solutions; silver salts; fountain-pen points; cyanide solutions; platinum-clad metals; chemical ware; contact points, etc.

The purpose of the book is to provide adequate information on the recovery and refining of precious metal wastes, the equipment needed, and the process involved; the economic aspects are constantly kept in view, and the language is clear, non-technical, and easy to understand. The book is simple and explicit enough for the beginner, and contains a fund of information for the more experienced. In many respects it is of an outstanding character, and in its special field will be invaluable to those in the jewellery and dental trades.

By C. M. HOKE. Published by Metallurgical Publishing Co., 123, William Street, New York, N.Y., U.S.A. Price $5·00.

Strength of Materials

THE subject of this book includes the study of the distribution of internal forces, the stability and deformation of various elements of machines and structures subjected to straining actions. It is founded partly on the result of experiment and partly on conclusions drawn therefrom by the application of the principles of mechanics and mathematics. Except in very simple cases, the demonstrations are less rigorous than those which form the mathematical theory of elasticity, an exact science which is unable to furnish solutions for the majority of the practical problems which present themselves to the engineer in the design of machines and structures. The semi-empirical nature of the subject makes it desirable that its formulæ should, wherever possible, be tested by experiment, and that in all cases the limits within which the theories may represent the facts should be clearly appreciated. In proportioning the parts of machines and structures, various considerations, other than strength and stiffness, play an important part, but rationally used, the results obtained in the subject of strength and materials form an important part of the basis of the scientific design of machines and structures.

Originally published in 1908, the present is the ninth edition and completes 52,000 copies, surely a record on this subject by any author. Almost since the book was originally published it has been accepted as a standard textbook on the subject which covers the requirements of the degree examinations of universities, the examinations of professional institutions and of the Higher National Certificates in Mechanical Engineering. Primarily written for engineering students, it is widely used by those concerned with the design of machines and structures. The need for resetting the type for this edition has given an opportunity for more complete revision than was possible in the many earlier editions. Thus, in those parts of the subject in which research or development has made change desirable, chapters or articles have been re-written. Notable instances are the work on fatigue, criteria of elastic strength,

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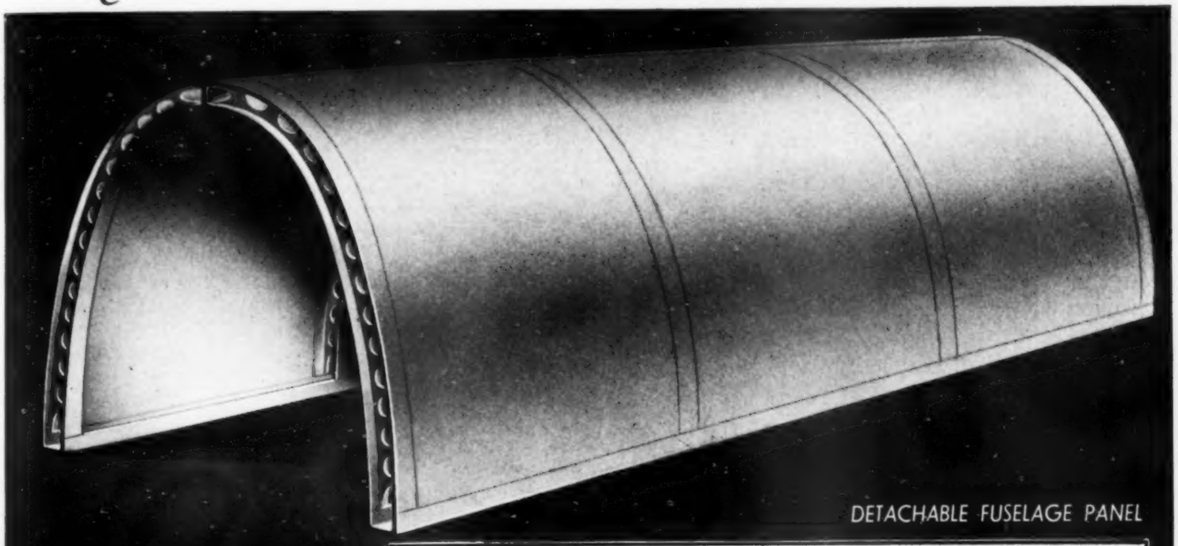

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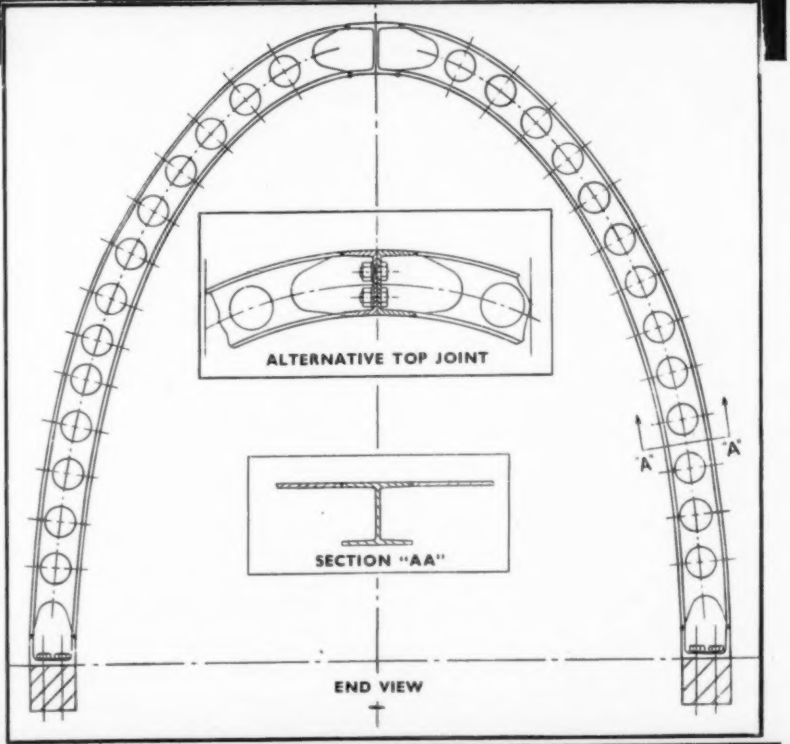

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creep, metallurgical developments of ferrous metals and methods of testing. More use, too, has been made of elastic strain energy and the theorems related to it for the determinations of elastic deformations.

This book is of outstanding merit and will remain for many years to come a standard work on strength of materials.

By Arthur Morley, O.B.E., D.Sc., M.I.Mech.E. Published by Longmans, Green and Co., Ltd., 39, Paternoster Row, London, E.C. 4. Price, 15s. net.

Refractory Materials:

Their Manufacture and Use

We are so accustomed to the use of high temperatures in various manufacturing processes that we sometimes forget how much they depend on materials which will withstand the effects of high temperatures. Many of these processes could not be carried out without the use of a material, not only capable of resisting the temperature at which the operation is performed, but which offers resistance to the temperature under conditions determined by the performance of the particular process. But the manufacture and preparation of these refractory materials have always been associated with these processes and efforts are continually being made to improve existing materials or to develop new ones likely to be more serviceable in use.

There is an increasing need for highly refractory materials, expecially to satisfy the exceptionally severe requirements of many modern processes—e.g., electric steel melting and a proper study of the subject is necessary to the achievement of success. With this in view, the book under consideration gives a very comprehensive account of the progress to date, and provides the basic information for further development. It summarises in convenient form the chief materials and products used in the construction of furnaces, etc., and describes the manufacture and properties of firebricks, retorts, crucibles, etc., used in the metallurgical, engineering, chemical and other industries. It is intended to supply the user of refractory materials with the main properties of the materials and products available to him, whilst the manufacturer will also find detailed descriptions of the raw materials, the methods of preparation, manufacture and use.

This book is one of the few published that is devoted solely to this important subject. It was originally published in 1917, and the manner in which it has been received by users and manufacturers of refractory materials is indicated by the fact that this volume is the third edition. This edition has been brought up to date by the inclusion of the progress achieved since the previous edition. But the amount of research work and other sources of information which have been made available since the last edition is so large that a careful selection has been necessary to keep the size of the book within reasonable dimensions. Since it is chiefly used by men in close contact with the actual manufacture of refractory materials, attention has been given more especially to the inclusion of information of more immediate practical importance.

The author points out that the possibilities for future developments in refractory materials depend on the recognition that such substances consist essentially of a heat-resisting substance and either a fusible substance or a substance which can combine chemically with other substances present and so produce a fusible substance; the recognition that, as the temperature rises or the time of exposure to a high temperature is prolonged, the amount of fused substance increases, and will eventually be present in such a proportion that the material as a whole ceases to resist the action of heat and becomes soft and distorted, or actually melts and drops out of place; the recognition that slags and other substances react chemically with refractory materials with which they come in contact, thereby increasing the proportion of fused material in the refractory one.

When these facts have been adequately recognised, the line of improvement will consist in the selection of materials in which the rate of formation of fused material is very slow; materials which do not readily dissolve in the fusible matter formed during use; materials with a minimum surface offered to contact with fluxes or abrasives, implying refractory materials of low porosity; materials which have been preheated to a much higher temperature than they are likely to attain when in use, so as to prevent any serious change in volume during the period of use; and shapes which can be laid with the thinnest practicable joints.

In its enlarged and revised form this volume will continue to be of service to all who use refractory materials as well as to those who are striving to improve products in this important field. Comprising nearly 900 pages, with 173 illustrations, the book is a mine of information; it is admirably produced and can be recommended not only as a textbook on the subject, but as a book of reference.

By Alfred B. Searle, Cantor Lecturer on Brickmaking. Published by Charles Griffin and Co., Ltd., 42, Drury Lane, London, W.C. 2; price 45s. net.

Soviet Manganese

A survey of the manganese deposits in Bashkiria, estimated to contain several million tons, is in progress. These deposits, it is believed, will become a source of supply for the Magnitogorsk Iron and Steel Works in the Urals. The prospecting to be carried out is part of a general scheme to study the manganese resources in the Urals and in Siberia, the aim being to eliminate the need to transport manganese ores over thousands of miles for the iron and steel industry in the Soviet East. The efforts of Soviet geologists have brought to light two large deposits in the Sverdlovsk Province (in the Urals) and deposits in West Siberia, estimated to contain many millions of tons of manganese ores.

It is noteworthy that experiments conducted over a long period in mining manganese ore by hydraulic methods have just been successfully completed. The inventors of the method are two Russian engineers, Z. Shakhrin and E. Ilyinsky, who designed a plant built for the mining of the ore, comprising a pumping station, set up at the shaft of the mine, which pumps water from a nearby river and, under a pressure of 14–22 atmospheres, sends it down to hydro-monitors and hydro-elevators. At the drift, a vein of manganese ore 65 ft. wide and 8¼ ft. thick is subjected to the destructive impact of two hydro-monitors. Hydro-elevators standing alongside the monitors suck up the broken ore and deliver it to the surface under high pressure; thence it is further transported by water along special pipes to the concentration factory.

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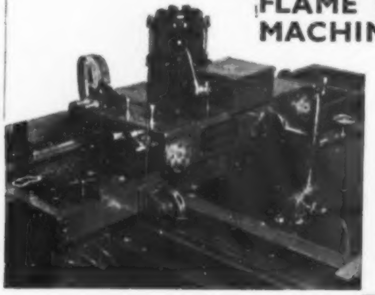

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Joshua Bigwood & Son, Ltd., Wolverhampton.

Machine Tools
Sanderson Brothers and Newbould Ltd., Sheffield.

Magnesium Alloys
F. A. Hughes Ltd., London.
Magnesium Castings, Ltd., Slough.
Sterling Metals, Ltd., Coventry.

Magnetic Separators, Clutches, Chucks, and Lifting Magnets
Electromagnets, Ltd., 48, High St., Erdington, Birmingham.
General Electric Co. Ltd., London.

Metal Spraying
Metallisation Ltd., Dudley.

Motors (Electric)
General Electric Co. Ltd., London.
Metropolitan-Vickers, Ltd., Trafford Park, Manchester.

Naval Brass Ingots
McKechnie Bros. Ltd., Rotton Park St., Birmingham.

Non-Ferrous Metals
Birmetals, Ltd.
Reynolds Tube Co., Tyseley, Birmingham.
I.C.I. Metals Ltd., Kynoch Works, Witton, Birmingham, 6.
McKechnie Bros. Ltd., Rotton Park St., Birmingham.